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HEAVY FLAVORS IN e^+e^- INTERACTIONS

by

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Heavy Flavors in $e^+ e^-$ Interactions .

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Recently a considerable amount of both theoretical and experimental effort has been given to Heavy Flavor Physics , mainly since

- The $Q\ \overline{Q}$ system is simple . Spectroscopy and successful calculations are possible .
- A *good* separation of the Heavy Flavors (Jets , Mesons) is possible.

So , ***Single Flavor Jets*** or isolated processes can be studied in analogy to $\mu \to e\overline{\nu}_e\nu_\mu$ decays.
Therefore :

1. We can determine the Standard-Model parameters like masses , and the K-M matrix.
2. We can check the validity of the Standard-Model by the absence of forbidden processes.
3. We can test for flavor independence required by QCD .
4. We can find possible clues for new physics, for 4^{th} generation effects, for new CP-violations in B^0 decays and others.

1 Introduction

1.1 Historical comments :

The experimentation of Heavy Flavors began with the discovery of the $J/\Psi(3097)$ and shortly after the $\Psi'(3685)$ in November 1974 .

The spectroscopy of CHARM started immediately , but the expected charmed-mesons, $c\overline{u}$ $c\overline{d}$ etc , were discovered only $1\frac{1}{2}$ years later, and some (the F^* -see Fig.1) only after 9 years[1].

- 1977: The Υ is discovered[2] in $P + A \to \mu^+ \mu^- + X$ at FNAL .
- 1978: The $\Upsilon_{1S}(9460)$ and the Υ_{2S} were seen at DESY[3] and two years later at CORNELL[4] (Fig. 2).
- 1983: Evidence for the B-Mesons starts to be accumulated (B-Meson seen in the CLEO[5] experiment) (Fig. 3).
- 1984-5: Beautiful examples of *Beauty* decay are seen directly by visual techniques[6] (Fig. 4). The B^* is seen and the $B^* - B$ mass difference is determined[7] .

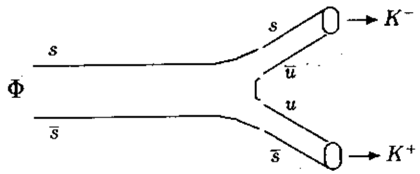
In general , so far , the production and decays of Heavy Flavors is essentially explained by the Standard Model of Electro-Weak interactions, including all QCD effects. So far , no deviations from the Standard Model have been reported, even though we know that it cannot be complete , for several reasons like :

1. The Generation problem :
   (a) Why are there Generations ?
   What distinguishes them (masses , angles) ?
   (b) Why 3 Generations ? Are there more ?
2. Why does the electron have the same charge as the proton ?
   Are quarks and leptons connected ?
   (a) Does it imply that leptons and quarks are made from the same fundamental constituents ?
   (b) Do they belong to the same representation in a grand unification scheme?
3. Many open questions , like $\mu \to e\,\gamma$ decays , etc.

Thus , testing the Standard Model again and again is crucial, in order to find an experimental hint in which direction the new physics beyond the Standard Model goes. (detailed discussion given by H. Harari , this conference)

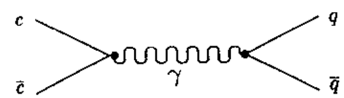
1.2 Decays : Zweig Rule

The ρ,ω,ϕ decay strongly into hadrons since its original quark and anti-quark continue into the final state as constituents of the final mesons, viz $\Phi \to K\overline{K}$



$BR(\Phi \to K\overline{K}) = 85\%$

But the decay $\Phi \to \rho\pi$ is already suppressed (only 15% BR) in spite of the bigger phase space factor it has. This is essentially the Zweig rule : Reactions in which the original quarks disappear are suppressed .
For the case of the J/Ψ , or Υ , the above favored form of constituent continuation is energetically forbidden $(2*M(D^0) > M_\Psi)$. Thus they decay via high order QCD diagrams, or electromagnetic annihilation :



As a result , the J/Ψ and Υ decays are slow, and they are narrow states.

1.3 The KOBAYASHI–MASKAWA matrix :

Back in 1972 , prior to the charm discovery , Kobayashi and Maskawa[8] considered the electro-weak theory with 4 colored quarks and 4 leptons in

$$SU(3)_C \times SU(2) \times U(1)$$

broken by one minimal Higgs doublet .
They observed that this theory with :

$$\begin{pmatrix} u \\ d \end{pmatrix}_L \begin{pmatrix} c \\ s \end{pmatrix}_L \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L , \; u_R \, , \, d_R \, , \, c_R \, , \, s_R \, , \, e_R \, , \, \mu_R$$

and (H^0) , $W^\pm$, Z^0 ,γ and Gluons, while having the GIM mechanism[9] and suppressing FCNC (Flavor – Changing – Neutral – Currents) is indeed CP invariant, since U (the quark mixing matrix) is real .

$$U \;=\; \begin{matrix} u \\ c \end{matrix} \begin{pmatrix} \cos\theta_C & \sin\theta_C \\ -\sin\theta_C & \cos\theta_C \end{pmatrix}$$

$$d \qquad s \qquad \theta_C = \text{Cabbibo angle}$$

To obtain CP–violation , they introduced a 3^{rd} generation ,

$$\begin{pmatrix} t \\ b \end{pmatrix}_L \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$$

In this theory the charged current for quarks will be of the form :

$$J_\mu \;=\; (\bar{u}\,\bar{c}\,\bar{t}\,)_L \;\gamma_\mu\; U_{KM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L$$

U_{KM} is a 3×3 unitary matrix , describing the mixing in the quark sector.
This matrix has one phase δ which is arbitrary and if $\delta \neq 0$ one can get CP-violation in $K_L{}^0 \to \pi\pi$. (over-all phases are absorbed into the coefficients).
Later[10] it was shown that with 6 quarks a model of observable CP non – conservation in $K_L{}^0 \to \pi\pi$ decay can be built , with little or no effect elsewhere.
The Kobayashi–Maskawa matrix was given as :

$$U \;=\; \begin{pmatrix} c_1 & -s_1 c_3 & -s_1 s_3 \\ s_1 c_2 & c_1 c_2 c_3 - s_2 s_3 e^{i\delta} & c_1 c_2 s_3 + s_2 c_3 e^{i\delta} \\ s_1 s_2 & c_1 s_2 c_3 + c_2 s_3 e^{i\delta} & c_1 s_2 s_3 + c_2 c_3 e^{i\delta} \end{pmatrix}$$

$$c_i = \cos\theta_i \;,\; s_i = \sin\theta_i \;,\; i = 1,2,3$$

θ_1 , θ_2 , θ_3 are 3 angles equivalent to the Euler angles , and δ is the above phase .
This matrix has also other representations , and will be discussed later .
The quark mass eigenstates (d,s,b) are related to the weak interaction eigenstates (d',s',b') by this matrix : q'=U · q
Alternatively , it specifies the quark couplings in the charge changing weak interaction current :

$$J^\mu \;=\; \bar{q}^\dagger \,\gamma^\mu\, (\,1\; - \gamma_5\,)\, U\, q$$

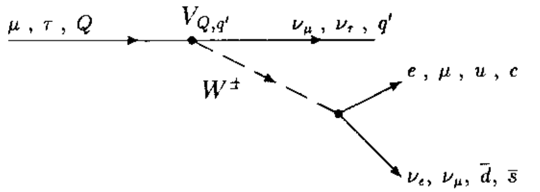
Several alternative forms of the K–M matrix have been used in the past few years.

A crucial experimental task is to determine the parameters of the K–M theory and thereby test the Standard Model . Obviously only Heavy Flavor physics can offer a complete determination of the K–M matrix, by life–time measurements, reaction rates, CP violation in the K_L^0 decays and perhaps eventually in B^0 decays.
In this review we shall concentrate on recent quark (c and b) life–time measurements (see section 2), heavy quark fragmentations (see section 3) and finally on some "exotic" decays (see section 4).

2 Heavy Quark Life Times

2.1 Life–Times , General :

Within the standard electro–weak theory all flavor changing transitions between quarks and leptons are due to $W^\pm$ coupling (no FCNC are allowed):



so we have a Universal Weak coupling for all Fermions , if one can neglect flavor–mixing final state interactions and take the Kobayashi–Maskawa coupling $V_{Q,q}$ to be ≈ 1 for Heavy Quarks.

Indeed : $|\,V\,| \approx 1$ **for Cabbibo Allowed Diagonal Transitions**

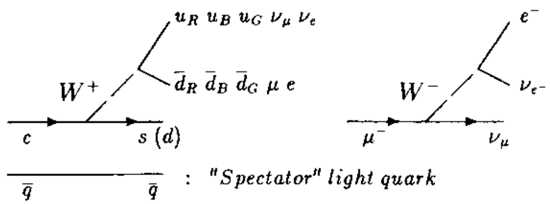
Then we have (B_e is the electronic branching ratio):

$$\frac{1}{\tau_L} = \frac{1}{B_e} \times \frac{G_F{}^2}{192\pi^3} \times M_L{}^5 \;,\; \frac{1}{\tau_Q} = \frac{1}{B_e} \times \frac{G_F{}^2}{192\pi^3} \times M_Q{}^5$$

Note the extreme sensitivity to the mass : 5^{th} power .

2.2 Decay rates and Life–Times :

Let us compare the semi–leptonic decays of charmed mesons and muons :



The spectator model diagrams seemingly account for most of the decay rates. In this approximation the Charm decay rates are :

$$\Gamma_{c,tot} = 5 \left(\frac{M_c}{M_\mu} \right)^5 \Gamma(\mu \rightarrow e \nu \bar{\nu})$$

The factor 5 is due to the 3 colors and 2 possible leptonic W decay modes in c decay .

2.2.1 Semi-Leptonic branching ratios :

Since in general one has :

$$\text{life-time } \tau \sim \frac{1}{\Gamma_{tot}} \quad , \quad B.R. = \frac{\Gamma_\ell (D \rightarrow \ell \nu X)}{\Gamma_{tot} (D \rightarrow all)}$$

$$\text{and clearly } \Gamma_\ell \left(D^+ \rightarrow \ell \nu X\right) \equiv \Gamma_\ell \left(D^0 \rightarrow \ell \nu X\right)$$

therefore :

$$\frac{\tau(D^+)}{\tau(D^0)} = \frac{1 / \Gamma^+_{tot}}{1 / \Gamma^0_{tot}} = \frac{\Gamma^+_\ell / \Gamma^+_{tot}}{\Gamma^0_\ell / \Gamma^0_{tot}} = \frac{BR(D^+ \rightarrow \ell \nu X)}{BR(D^0 \rightarrow \ell \nu X)}$$

Thus the semi-leptonic branching ratios of the D^+ (D^0) and their life-times are related in a simple way .

Furthermore , measuring the life-times gives us information on the Kobayashi-Maskawa matrix elements relevant to the Q-transitions since the complete expression is :

$$\frac{1}{\tau_Q} = \frac{1}{B_e} \times \frac{{G_F}^2}{192\pi^3} \times {M_Q}^5 \times \sum_i | U_{Q,q_i} |^2$$

2.2.2 The τ lepton :

Let us use as an example the τ lepton life-time. A recent experimental life-time compilation is given in Fig. 5.

$$\tau_\tau(meas.) = (2.95 \pm 0.25 \pm 0.35) \cdot 10^{-13} sec.$$

From the theory (sec. 2.1) we get :

$$\tau_\tau(calc.) = (2.82 \pm 0.18) \cdot 10^{-13} sec.$$

(uncertainty from $B_e(\tau)$=0.176 ± 0.011)

The agreement between theory and experiment is excellent.

Comparison of the τ and μ life-times yields a test for lepton universality. The ratio of the weak constants is

$$\frac{G^\tau_F}{G^\mu_F} = 0.97$$

2.2.3 c-quark life-time measurement :

Sufficient data on the c-quark decays became available recently , so that individual determinations of the life-time of the charm mesons is possible :

$$D^+ = c\ \bar{d} \quad , \quad D^- = \bar{c}\ d$$
$$D^0 = c\ \bar{u} \quad , \quad \overline{D^0} = \bar{c}\ u$$
$$F^+ = c\ \bar{s} \quad , \quad F^- = \bar{c}\ s$$

The main Feynman graphs related to charmed mesons decays are given in Fig. 6 . Different diagrams can contribute to D^+ and D^0 decays and thus their decay rates need not to be equal. In particular, if the W - exchange contribution to D^0 decay is large, one expects $\tau(D^0) < \tau(D^+)$.

The life-times are usually obtained by measuring the event impact parameter distributions defined in Fig. 7. Alternatively one uses directly the flight - path - measurements in the vertex reconstruction method, in which the secondary vertex is reconstructed by several tracks and its distance from the main vertex is determined.

Examples will be given for the usage of each method.

Direct life-time determinations are possible only at energies well above threshold and not in the "D-factory region". Consequently, one does not have high statistics measurements of D - life-times. In order to overcome resolution problems at high energy one usually selects D's by imposing sharp cuts on the mass - difference between the $D^{*+}(K^-\pi^+\pi^+)$ and $D^0(K^-\pi^+)$; since the decay $D^* \rightarrow D$ has a tiny Q-value most of the measurement errors cancel out and one obtains very narrow and clean peaks in the distribution of the quantity : (the c.c. states are also included)

$$\delta M = M(K^-\pi^+\pi^+) - M(K^-\pi^+)$$

corresponding to $D^{*+} \rightarrow \pi^+ D^0$ followed by $D^0 \rightarrow K^-\pi^+$, and similar ones for other decay modes. Several recent distributions of δM, obtained at PETRA[11] and PEP[12] , are shown in Fig. 8 and Fig. 9 respectively. In all cases the background is small and one then uses the events in the peak for life-time measurements.

In a recent experiment at PEP , MARK II[12] obtained the life-time distributions of D^0 (73 events , $D^0 \rightarrow K\pi, K\pi\pi^0$) and D^+ (23 events, including 7 ± 2.6 background events, from $D^{*+} \rightarrow D^+\pi^0, D^+ \rightarrow K^-\pi^+\pi^+$ decay). They obtained, from maximum likelihood fits to the data (see Fig. 10):

$$\tau(D^0) = (4.4^{+0.9}_{-0.8} \pm 0.5) \cdot 10^{-13} sec.$$

$$\tau(D^+) = (8.5^{+3.4}_{-2.5} \pm 0.5) \cdot 10^{-13} sec.$$

The (preliminary) HRS[12] results (Fig. 11) for D^0 also yield similar values and the recent compilation[13] of D life-time gives: (see Fig. 12)

$$\frac{\tau(D^+)}{\tau(D^0)} = 2.4 \pm 0.3$$

As mentioned above , neglecting Cabibbo suppressed modes this can be directly compared with the D^+/D^0 electronic branching ratios.

In a recent experiment MARK III[14] measured these decay modes and obtained: (see Fig. 13)

$$\frac{BR\,(D^+ \to \ell XX)}{BR\,(D^0 \to \ell XX)} = 2.3^{+0.5}_{-0.4} \pm 0.1$$

We see that they are in excellent agreement.
- So another piece of our current understanding fits into the puzzle.
Other Charmed Mesons and Baryon life-times are not yet well determined.
For example : $F^{\pm}$, Λ_c . see Fig. 14 (from ref. 13)

2.2.4 b-quark life-time measurement :

Here the situation is much more difficult since very few B-Mesons have been identified , in exclusive decays . Thus , the standard method is to use semi-leptonic decays and to measure the impact parameter distribution for the muonic and the electronic events. Alternatively, one is using the vertex reconstruction method, in events having final state leptons, or selected events which are b - *decays enriched* compared with b - *depleted*[13].
The most recent results are :

1. Lepton sample : MAC'84 results[15] see (Fig. 15) , impact parameter method : 505 events , $< d >= (70 \pm 22 \pm 10)\mu$

   $$\tau b = (\,0.81 \pm 0.28 \pm 0.17\,)\cdot 10^{-12} sec.$$

2. MARK II'85 results[16] :

   (a) by decay length distribution of the secondary reconstructed vertex, in events having a high P and a high P_T lepton as a tag (P > 2 GeV/c , P_T > 1 GeV/c) , see Fig. 16 :
   551 events , $< l >= (413 \pm 43)\mu$

   $$\tau b = (\,1.25\,^{+0.26}_{-0.19} \pm 0.5\,)\cdot 10^{-12} sec.$$

   (b) by impact parameter method (see Fig. 17) :
   551 events , $< d >= (80 \pm 17)\mu$

   $$\tau b = (\,0.85 \pm 0.17 \pm 0.21\,)\cdot 10^{-12} sec.$$

3. Hadron sample : TASSO'85[17] results (see Fig. 18)
   Used average impact parameter of all tracks in a b *enriched* sample and compare to b *depleted* sample (and M.C.)
   9000 tracks in b *enriched sample*, $< d > \approx (100 \pm 17)\mu$

   $$\tau b = (\,1.57 \pm 0.32 \pm 0.35\,)\cdot 10^{-12} sec.$$

Note :*Since TASSO does-not demand leptons, they are measuring a true average of the b life-time, but it could be different from the life-time measured in leptonic b-decays.*

A summary of all B-Meson life-times is given in Fig. 19. The b life-time is longer then the c life-time in spite of its higher mass (by a factor $\approx$ 3.3) which would require, in the simple minded picture, a life-time shorter by a factor of $3.3^5 \approx 400$ than the c life-time. This shows that transitions from 3^{rd} to 2^{nd} generation are strongly suppressed as compared with transitions from 2^{nd} to 1^{st} generation .

2.3 Determining the KOBAYASHI–MASKAWA matrix:

Consider K-M representation :

$$U = \begin{pmatrix} U_{ud} & U_{us} & U_{ub} \\ U_{cd} & U_{cs} & U_{cb} \\ U_{td} & U_{ts} & U_{tb} \end{pmatrix}$$

The diagonal elements are expected to be large since they represent transitions within the same *generation* (Cabbibo allowed).

1. The element U_{ud} $(u \rightleftharpoons d)$ is best known from β decay , and has the value[18]

   $$U_{ud} = 0.9733 \pm 0.0024$$

2. The element U_{us} $(u \rightleftharpoons s)$ is responsible for strange particle decays and measures basically the Cabbibo angle.
   Analysis of K_{e3} decays[18] :

   $$K^+ \to \pi^0\, e^+\, \nu$$
   $$K^0 \to \pi^{\pm}\, e^{\mp}\, \nu$$

   and from the CERN hyperon decay experiment[19] yields the average "best value" :

   $$U_{us} = 0.225 \pm 0.005$$

2.3.1 Charm transitions :

$$U_{cd}(c \to d)$$

Again , semileptonic decays of the type

$$D \to \pi\, \ell\, \nu$$
$$D \to \rho\, \ell\, \nu$$

are best suited since final state interaction can be neglected.

Until recently , there existed little data on these *Cabibbo supressed* decays. However one can get a fair estimate of this term by the study of Cabibbo supressed hadronic D-decay, as was done now by MARK III[20] (see Fig. 20).

They get :

$$\frac{\Gamma\,(D^0 \to K^- K^+)}{\Gamma\,(D^0 \to K^-\pi^+)} = 0.122 \pm 0.018 \pm 0.012$$

$$\frac{\Gamma\,(D^0 \to \pi^-\pi^+)}{\Gamma\,(D^0 \to K^-\pi^+)} = 0.033 \pm 0.010 \pm 0.006$$

These reactions ratios should have been equal and measure (except for the phase-space corrections)

$$\approx \left| \frac{U_{cd}}{U_{cs}} \right|^2$$

under the assumption of exact SU(3), no final state interactions[21],
and $U_{cd} \approx U_{us}$.

From the K* and K , ρ^+ and π^+ final states they get

$$\frac{|U_{cd}|^2}{|U_{cs}|^2} = 0.05 \pm 0.03$$

This then yields (taking $|U_{cs}| \approx 1$)

$$|U_{cd}| \approx 0.23^{+0.05}_{-0.10}$$

From detailed analysis of ν-reactions CDHS[22] found :

$$|U_{cd}| = 0.24 \pm 0.03$$

Thus we obtain the nice result : $U_{cd} \approx U_{us}$, for the first non-diagonal element.

2.3.2 Charm favoured decays :

$$U_{cs}(c \to s)$$

U_{cs} can be determined from the D life-times and the semileptonic B.R. :

$$\frac{BR(D \to K\, e\, \nu)}{BR(D \to e + X)} = 0.55 \pm 0.1$$

Using :

$$\Gamma\left(D^+ \to \overline{K^0}\, e^+\, \nu_e\right) = 1.5 \times 10^{11} sec^{-1} \times \left|f_+^{D\to K}(0)\right|^2 \times |U_{cs}|^2$$

and taking $|f|^2 \approx 1$ (SU_4 symmetry,Sakurai[23]) we get:

$$|U_{cs}| = 0.82 \pm 0.13$$

Other derivations, which depend on unitarity assumptions[23],and using data from ν experiments we have :

$$|U_{cs}| = 0.972 \pm 0.002$$

Thus also , $U_{ud} \approx U_{cs}$.

2.3.3 b-Matrix Elements ,U_{cb} ,U_{bu} :

$$(b \to c, b \to u)$$

Again , the best method is to study these matrix elements by observing direct b-decay:

$$\frac{\Gamma(b \to u\, \ell\, \nu)}{\Gamma(b \to c\, \ell\, \nu)}$$

In nice and beautiful experiments CLEO[24] and CUSB[25] measured the e and μ spectrum in the Υ(4s)–B semi leptonic decays ; (see Fig. 21)
The *upper-limits* both groups get on the $\frac{(b\to u)}{(b\to c)}$ ratio (90% C.L.) are :

- CUSB : < 5.5%
- CLEO : < 4%

Using the more stringent result of CLEO and *correcting* for phase space we get[24] :

$$\frac{|U_{ub}|}{|U_{cb}|} < 0.14\ (90\% C.L.)$$

$$\frac{|U_{bu}|^2}{|U_{bc}|^2} = p \cdot \frac{\Gamma(b \to u\, \ell\, \nu)}{\Gamma(b \to c\, \ell\, \nu)}$$

where p is the phase-space factor,p $\approx$ 2.1, for $m_b = 5.274 GeV$, $m_c = 1.7 GeV$, $m_u = 0.15 GeV$

From the b life-time we can get now $|U_{bc}|$, $|U_{bu}|$: We had above

$$\frac{1}{\tau_Q} = \frac{1}{B_e} \times \frac{G_F{}^2}{192\pi^3} \times M_b{}^5 \times \{0.45\,|U_{bc}|^2 + |U_{bu}|^2\}$$

The term in { } depends on the quark masses , and on *dynamical* enhancements of the *non-leptonic* modes ; see Gaillard and Maiani[26] .

Now using :

$$< \tau_b > = (1.1 \pm 0.2) \cdot 10^{-12}\ sec$$

$$BR = \frac{(b \to e)}{(b \to all)} = (11.6 \pm 0.5)\ \%$$

we get :

$$|U_{bc}| = 0.050 \pm 0.005$$

$$|U_{bu}| \le 0.010\ (90\%\ C.L.)$$

Note : *The b has a long life-time , since it cannot decay within its own generation - (only off diagonal elements). The decay t → b is expected to be fast and hence the t life-time to be short.*

Our knowledge of the Kobayashi–Maskawa can be **summarized** as follows.

Using all possible weak interaction data of **"old"** mesons and **heavy flavors** we get (assuming unitarity[23]):

$$|U_{ij}| = \begin{matrix} u: \\ c: \\ t: \end{matrix} \begin{pmatrix} .9737 \pm .0025 & .231 \pm .003 & < .0055 \\ .231 \pm .003 & .972 \pm .002 & .048 \pm .005 \\ < .015 & .048 \pm .005 & > .999 \pm .001 \end{pmatrix}$$

$$\qquad\qquad d: \qquad\qquad s: \qquad\qquad b:$$

This is obtained by determining the Kobayashi-Maskawa angles from the presently avaible data and calculating the transitions which are not directly observed.

We note that the matrix has the approximate form (phenomenologically)[27] :

$$|U| = \begin{matrix} 1^{st}\ Gen.: \\ 2^{nd}\ Gen.: \\ 3^{rd}\ Gen.: \end{matrix} \begin{pmatrix} 1 & X & X^3 \\ X & 1 & X^2 \\ X^3 & X^2 & 1 \end{pmatrix} ,\ X \simeq Cabibbo \approx \sin\Theta_c$$

There seems to be an hierarchy of the mixing strength (!) :

$$(1 \leftrightarrow 2) \gg (2 \leftrightarrow 3) \gg (1 \leftrightarrow 3)$$

As mentioned above (sec. 1.1) the origin of this order is not known and can not be explained by the standard model, just as the masses can not be explained within the model.
Recently, Fritzsch[28] proposed an *"Ansatz"* on the quark mass matrix form, relating the mixing angles to the ratios of the quark masses. He obtains, for example,

$$| U_{us} | \approx | U_{cd} | \approx \sqrt{\frac{m_d}{m_s} + \frac{m_u}{m_c}} \approx 0.23 \quad \textit{in good agreement !}$$

Clearly, much more work is required, both therotically and experimentally, in determining all angles and phases in the model, for a complete test of the theory.

3 Heavy Quark fragmentations

A good way to determine quark masses is via fragmentation. The fragmentation of heavy quarks will involve in general the emission of a heavy flavor hadron and of several light quark hadrons. Hovewer, for kinematical reasons, a larger amount of the original quark energy is taken up by the $Q\bar{q}$–meson, compared with the light quark fragmentation (Bjorken[29], Suzuki[29]). The kinematical effect can be easily visualized by considering the hypothetical example

$$p + \bar{p} \rightarrow (Hydrogen\ Atom) + \overline{(Hydrogen\ Atom)}$$

one would get then :

- All final state momenta of H and $\overline{H}$ are maximal.
- The proton takes the entire energy and the electrons almost none.

3.1 Fragmentation Functions :

The fragmentation is parametrized by a scaling function :

$$f(Z)\ , \quad Z = \frac{(\ E\ +\ p_{\parallel}\ )\ meson}{(\ E\ +\ p_{\parallel}\ )\ quark}$$

Peterson[30] (1983) proposed a fragmentation function of the form :

$$f(Z) = \frac{1}{Z\ (\ 1\ -\ \frac{1}{Z}\ -\ \frac{\epsilon_Q}{1-Z})^2}$$

$$\text{with : } \epsilon_Q \simeq \left(\frac{m_q}{m_Q}\right)^2$$

In practice , one uses "practical" Z definitions :
For $e^+ \ e^-$

$$Z \equiv X_E = \frac{E_{meson}}{E_{beam}}$$

or :

$$Z \equiv X_p = \frac{|p|_{meson}}{(E_b^2 - m_{meson}^2)^{\frac{1}{2}}}$$

But , X is different from Z because :

1. Due to perturbative QCD gluon emission $E_{quark} < E_{beam}$ at the beginning of the fragmentation , hence : $X \leq Z$.
2. QED corrections in the initial state (bremstrahlung) **reduces** E_{quark}.
3. At high energies some c–quarks are already decays of b–quarks , especially at low X .

Note: *All the above effects are energy dependent.*

Thus , in order to obtain a **consistent picture** and to **compare** experiments at different energies , the above effects must be corrected for[31].
(see also analysis in ref 40)

We roughly expect :

$$\epsilon_c \sim \left(\frac{0.3-0.5}{1.5}\right)^2 \simeq 0.1 \qquad\qquad \epsilon_b \sim \left(\frac{m_c}{m_b}\right)^2 \cdot \epsilon_c \simeq 0.01$$

A qualitative example of the expected heavy quark (D*) fragmentation functions, f(Z), and the above corrections are shown in Fig. 22.

Note : *While for the determination of ϵ_c data at all energies can be used, for $< Z >$ only the PEP/PETRA data is used , since at lower energies , because of the threshold in $Z = \frac{E_{had}}{E_{beam}}$ of 0.3 - 0.4, the Z-range is small.*

3.2 c – quark fragmentation :

3.2.1 D – mesons :

A large amount of new data on heavy quark fragmentation was presented recently from both PETRA and PEP experiments. Some of the old results on the $D^{*\pm}$ are shown in Fig. 23, from which the value[32] $\epsilon_c \simeq 0.25 \pm 0.1$ is obtained.
The 1985 data is much more accurate and we show in Fig. 24 – 25 some new HRS D – meson data[33] (based upon a luminosity of 255 pb^{-1} and excellent momentum resolution , $\delta p/p = 0.2p$ (GeV) %) as well as the scaled $D^{*\pm}$ cross sections (in Fig. 26 – Fig. 29) for the reaction

$$e^+ + e^- \rightarrow D^{*\pm} + X$$

from TPC/PEP–4[34] , DELCO[35] , HRS[36] and JADE[37] .

They all seem to converge to a value of ϵ_c of about 0.25 – 0.30 and a value of $\langle Z \rangle$ of $\simeq$ 0.5 – 0.65. This will be further discussed later on.

3.2.2 c – fragmentation for F mesons :

Since $F \equiv c\bar{s}$ ($\bar{c}s$), one expects to find $\epsilon_F > \epsilon_D$, and to obtain a somewhat softer fragmentation function. The world F data is still meager[1,38], but the above statements do not seem to be contradicted . (see[39] Fig. 30 – 31).

3.3 b–quark and c–quark fragmentations from semi–leptonic decays:

Since sizeable sample of B – mesons in specific decay modes are not yet available, the only way to study b – fragmentations is in semi – leptonic decays and this involves a statistical separation of c and b – events. Thus we shall treat both together in one sub–section.

There are, in general, three main sources contributing to the semi – leptonic final states in high energy e^+e^- interactions:

1. $b \rightarrow c \, \ell \, \nu_e$
2. $c \rightarrow s \, \ell \, \nu_e$
3. $b \rightarrow c + x \rightarrow c \, \ell \, \nu_e + x$

In addition , in every overall search for leptons, the pure experimental backgrounds (converted photons, π^0 Dalitz decays and hadrons faking leptons) have of course to be substracted away from the leptonic spectra.

In most cases, the yields of reactions (1) – (3) above as well as the determination of $\langle Z \rangle$ and ϵ_Q, are obtained by comparing the data with the results of Monte Carlo calculations, utilizing existing models. Since the heavy quarks have a large mass difference, one is able, by introducing appropriate p, p_T, s (or t) cuts, to obtain *b – enriched* or *c – enriched* samples and reliably determine the parameters of interest in spite of the heavy utilization of the Monte Carlo model calculations .
We shall survey some of the recent results .

3.3.1 The TASSO results :

TASSO has presented lepton inclusive data from a luminosity of 75 pb^{-1} at $\sim \sqrt{s} = 34$ GeV
Both channel were studied :

$$e^+ e^- \rightarrow \mu^\pm + X$$

$$e^+ e^- \rightarrow e^\pm + X$$

Muon data :
From a sample of 1136 μ events with $p_\mu \geq 1.5$ GeV, they got[40] :

$$BR\,(\, b \rightarrow \mu + \nu + X\,) = (\, 11.7 \pm 2.8 \pm 1.0\,)\,\%$$

$$BR\,(\, c \rightarrow \mu + \nu + X\,) = (\, 8.2 \pm 1.2\,^{+2.}_{-1.}\,)\,\%$$

$$\langle Z_b \rangle = 0.85 \pm 0.11\,^{+0.02}_{-0.07} \;,\; \epsilon_b = 0.0025\,^{+0.03}_{-0.0025}\,^{+0.011}_{-0.0013}$$

$$\langle Z_c \rangle = 0.77 \pm 0.06\,^{+0.03}_{-0.11} \;,\; \epsilon_c = 0.006\,^{+0.017}_{-0.005}\,^{+0.05}_{-0.003}$$

$$with\; Z = \frac{(\, E + p_\parallel\,)_{had}}{(\, E + p_\parallel\,)_Q}$$

The Flavor Changing Neutral Current (95 % C.L.) upper–limits are :

$$BR\,(\, b \rightarrow \mu^+ \mu^- X\,) < 2\,\%$$

$$BR\,(\, c \rightarrow \mu^+ \mu^- X\,) < 0.7\,\%$$

Electron data :
From a sample of 1110 electron events with $p_e \gtrsim 1.$ GeV, they[41] have obtained (Fig. 32):

$$BR\,(\, b \rightarrow e^\pm + X\,) = (\, 11.1 \pm 3.4 \pm 4.\,)\,\%$$

$$BR\,(\, c \rightarrow e^\pm + X\,) = (\, 9.2 \pm 2.2 \pm 4.\,)\,\%$$

$$\langle Z_b \rangle = 0.84\,^{+0.15}_{-0.10}\,^{+0.15}_{-0.11} \;,\; \epsilon_b = 0.005\,^{+0.022}_{-0.005}\,^{+0.020}_{-0.005}$$

$$\langle Z_c \rangle = 0.57 \pm 0.10 \pm 0.06 \;,\; \epsilon_c = 0.19\,^{+0.29}_{-0.13}\,^{+0.17}_{-0.08}$$

for $p \geq 1$ GeV/c , $p_t \geq 1.5$ GeV/c . (Clean sample , 82 % prompt electrons).

3.3.2 The MARK–J results :

The MARK–J collaboration[42] studied the μ events , with $p_\mu > 1.5$ GeV/c, in the reaction

$$e^+ e^- \rightarrow \mu + hadrons$$

In order to get the fragmentation functions they did a simultanous fit to :

- T – thrust of hadronic events
- p – momentum of the μ
- p_T – transverse momentum of the μ relative to the T axis

They obtained the branching ratio of muonic decays B_c ,B_b , ϵ_b and ϵ_c , $\epsilon = \frac{m_q}{m_Q}$ (see Fig. 33) :

$$BR\,(\, c \rightarrow \mu + X\,) = (\, 8.8 \pm 0.7 \pm 1.1\,)\,\%$$

$$BR\,(\, b \rightarrow \mu + X\,) = (\, 12.4 \pm 1.3 \pm 2.\,)\,\%$$

$$\langle Z_c \rangle = 0.46 \pm 0.03 \pm 0.04 \;,\; \sqrt{\epsilon_c} = 0.79 \pm 0.11 \pm 0.15$$

$$\langle Z_b \rangle = 0.74 \pm 0.02 \pm 0.03 \;,\; \sqrt{\epsilon_b} = 0.164 \pm 0.024 \pm 0.059$$

They also fitted f(Z) independently at each Z–bin , and comfirmed the above values. The results of this fit is given in Fig. 34 .

3.3.3 The JADE results :

In a new measurement of the muon spectrum in the hadronic events, the JADE collaboration[43] has determined the semi–muonic branching ratios of b and c hadrons. They have fitted the μ – momentum distribution out of the event plane (P_{out} – distribution — see Fig. 35) and also the P_T distribution (μ – momentum $\perp$ to the Thrust axis), to Monte Carlo calculated distributions by a maximum likelihood fit.
The fit (also shown in Fig. 35) yields the following results :

$$BR\,(\, b \rightarrow \mu + \nu + X\,) = (\, 11.4 \pm 1.8\,)\,\%$$

$$BR\,(\, c \rightarrow \mu + \nu + X\,) = (\, 8.9 \pm 1.8\,)\,\%$$

These are in good agreement with the results of other experiments.

3.4 Summary :

The summary of all **up - to - date** fragmentation parameters is given in Fig. (table) 36 .
For the D* , after correction for QCD , QED , E_{cm} one gets the following value[31]: (see Fig. 37)

$$\langle Z_c \rangle = 0.71 \pm 0.014 \pm 0.03$$

Thus, the corrections indeed lead to good agreement between a large number of experiments. Further work is clearly required on all other c and b decay parameters.

<u>Consequences</u>

1. Since for D* ,from the above $\langle \epsilon_c \rangle$, the **Peterson** parameter $\epsilon_{c(D^*)}$ turns out to be about 0.04 , one calculates for the light u , d quarks a mass of 0.3 Gev with m_c taken as 1.5 Gev. This is reasonable for constituent u , d quark masses .
2. Since $m_s \approx 0.5$ GeV , we expect that :

   $$\epsilon_{c(F)} \approx 0.09 \quad \rightsquigarrow \quad \langle Z_c \rangle \approx 0.65$$

   Indeed the experiment shows (Fig. 31) that F fragmentation is **softer**.
3. For the B-meson , since $m_b \approx 5$ GeV we expect that :

   $$\langle Z_b \rangle \simeq 0.85$$

   again verified by experiment (Fig. 36) .

3.5 Direct b → c decays :

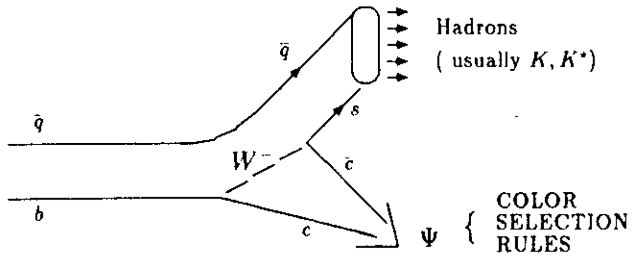
In concluding the fragmentation section we wish to quote a very nice and interesting result from CLEO[44], in which a first direct measurement of the decay $b \to c + e^- + \nu$ was reported (see Fig. 38). The experiment indicates that a large fraction of all b decays are compatible with the mode $b \to c + e^- + \nu$, and that the resulting D* momentum distribution agrees with the spectrum expected from the V-A decay of a point like B hadron ($B \to D^{*+} e^- \bar{\nu}$) of mass 5.275 GeV/c.

4 " Exotic " Effects

4.1 Observation of color suppressed reactions :

$$B \to J/\Psi + X$$

In the new (1985) data at the Υ(4s) runs , both at CORNELL(CESR)[45] and DESY(Argus)[46], the colored—suppressed reaction $B \to J/\Psi + X$ was seen (Fig 39-40).



Since the Ψ is a color singlet a suppression is expected. The result is :

$$CLEO : BR(B \to J/\Psi + X) = (1.10 \pm 0.21 \pm 0.23)\,\%$$

$$ARGUS : BR(B \to J/\Psi + X) = (1.37\,^{+0.6}_{-0.6})\,\%$$

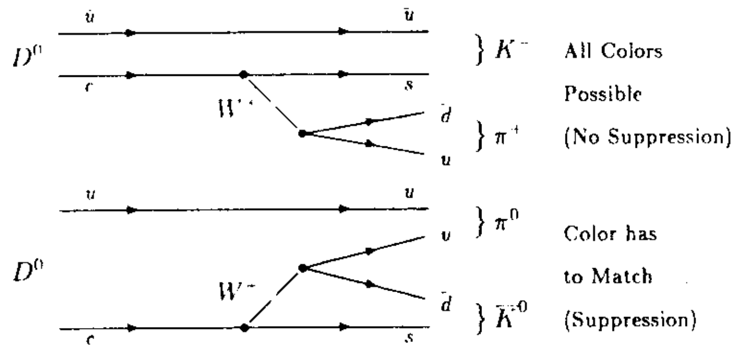
Prior to the experiments KÜHN and RÜCKL[47] have estimated it to be (1.6-2.4)%, and that the color-suppression (a factor of 3 in amplitude or a factor of 9 in rate) should be *cleaner* for heavy quarks (i.e. Ψ production) , since :

1. The light quark q above , cannot decay into a c quark , and must remain spectator .
2. The final state interaction of the Ψ + Hadrons is negligible (Zweig rule).
3. For Heavy Quark , soft gluon interaction is unimportant .

In fact , in light quark final states the **Color–Suppression** is not by a factor of 9 , but only by factor of 2 . { MARK III[48] , 1985 , (Fig. 41) }

$$\sigma_{D^0} \cdot BR(D^0 \to K^- + \pi^+) = (0.237 \pm 0.009 \pm 0.013)\ \text{nb}$$

$$\sigma_{D^0} \cdot BR(D^0 \to \overline{K^0} + \pi^0) = (0.108 \pm 0.020 \pm 0.010)\ \text{nb}$$



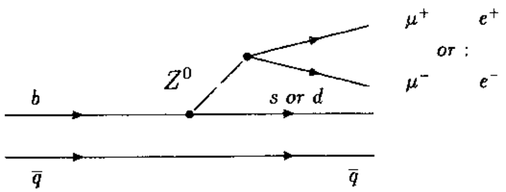
4.2 Search for Flavor Changing Neutral Currents and B^0-$\overline{B^0}$ Mixing :

4.2.1 Flavor Changing Neutral Currents :

The experimental **lack** of observation of strangeness changing neutral-currents, i.g. $K_L^0 \to \mu^+\mu^-$, was explained by the GIM[8] mechanism , which predicted the

4^{th} quark, charm . The generalisation of this to 6 quarks , means the absence of flavor-changing-neutral-currents altogether . {Note that 5 quarks models may have flavor-changing-neutral-currents }.

A flavor-changing-neutral-current , would lead to e.g. a symmetric pair of oppositely charged lepton.



Note that sequential decays :

$$b \rightarrow c \; \ell^- \; \nu$$
$$\downarrow$$
$$\longrightarrow s \; \ell^+ \; \nu$$

leads also to opposite sign leptons , , but $\mu + e$ pairs are possible.

MARK II has new results on this topic[49] , in which the 2 jets are separated (because of the high energies) , but they have a mixture of c and b jets.

CLEO[50] at the $\Upsilon(4s)$ had only b's (or c from b) , but no jet separation .

- The results are :
  - All data agree with the standard theory on neutral current. Flavor changing decays have not been found : with 90% C.L. CLEO gives a braching ratio for $(b \rightarrow \ell^+ \ell^- X) < 0.3\%$, for flavor-changing-neutral-current contributions.

4.2.2 $B^0 - \overline{B^0}$ mixing :

In exactly the same way that one has mixing in the $K^0 - \overline{K^0}$ system , one may have mixing in the $D^0 - \overline{D^0}$ and $B^0 - \overline{B^0}$ systems. Several authors have speculated that the $B^0_S - \overline{B^0_S}$ system should exhibit observable mixing (for a list of latest references see ref. 49).

The B^0_S system is :

$$B^0_S = b\,\bar{s} \;,\; \overline{B^0_S} = \bar{b}\,s \,.$$

Furthermore , the mixed states could be combined into :

$$\begin{cases} B^S_S = B_S + \overline{B_S} \\ B^L_S = B_S - \overline{B_S} \end{cases}$$

We shall have **large mixing** if the mass difference

$$(\Delta m = M(B^L) - M(B^S))$$

is large enough , so that the **phase** between B^L and B^S can change appreciably in one life-time $\tau \sim \frac{1}{\Gamma}$.

Thus the parameter : $\frac{\Delta m}{\Gamma}$ is a measure of the effect expected . In general one may also expect CP violating effects like for K^0 :

$$K^0_L = \frac{1}{\sqrt{1+|\epsilon|^2}} \bullet \left\{ \left|K^0_2\right\rangle + \epsilon \left|K^0_1\right\rangle \right\}$$

$$|\epsilon| = (2.27 \pm 0.08) \times 10^{-3}$$

$$B^0_L = \frac{1}{\sqrt{1+|\epsilon_B|^2}} \bullet \left\{ \left|B^0_2\right\rangle + \epsilon_B \left|B^0_1\right\rangle \right\}$$

It is of course an exciting possibility to observe and measure ϵ_B , and find another CP-violation in nature[23] .

(In the existing K-M matrix , a 0.1% → 1% effect is predicted).

The measure of the mixing is :

$$r_{d,s} = \frac{\Gamma\left(B^0_{d,s} \rightarrow \ell^-\right)}{\Gamma\left(B^0_{d,s} \rightarrow \ell^+\right)}$$

(here $B^0 = b$ containing hadron)

Other parameters are :

$$R = \frac{N^{++} + N^{--}}{N^{++} + N^{--} + N^{+-}} = \frac{r + \bar{r}}{r + \bar{r} + r\bar{r} + 1}$$

and the CP-violating parameter :

$$a = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

MARK II[49] in the full 220 pb^{-1} statistics obtained the following total lepton yields:

events seen			lepton cuts GeV	
sample	e's	μ's	$\lvert p \rvert$	$\lvert p_t \rvert$
b-enriched	574	362	> 2	> 1
c-enriched	1159	570	> 3	< 1

The limits they get are shown in Fig. 42 and in Fig.(table) 43 (di-leptons).

Thus , while with 90% C.L. , r_d is < 20 − 30% , $r_s = \frac{\Gamma(B^0_S \rightarrow \ell^-)}{\Gamma(B^0_S \rightarrow \ell^+)}$ could be rather large !

Future : Some calculation[51] (Cronin et al. , SNOWMASS'84) and estimates say that at the SSC they will have ~ 1300 events having a specific B_S meson decay in one year of running :

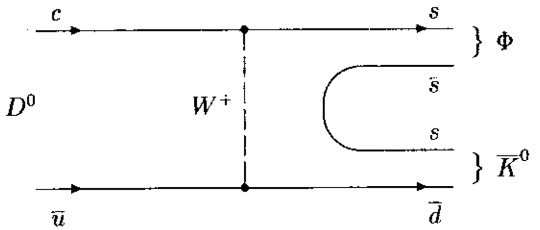
Then a measurement of $a_B = \frac{\ell^+ - \ell^-}{\ell^+ + \ell^-}$ could be attempted !!! However, it is conceivable that[51] the Z_0 decays in LEP/SLC will serve as **bottom–factories** in which the B_0 mixing and the CP violation will be determined later.

4.3 W – exchange in D^0 decays :

As a final point we would like to mention again W–exchange diagrams. In examining the $D^0 - D^+$ life–time , it was evident that the spectator diagrams **cannot** explain the data, since they would imply $\tau\ (D^0) = \tau\ (D^+)$, in contradiction to the data.

The possible importance of W – exchange diagrams — relevant only to D^0 decays — was mentioned .

Very recently (June 1985) ARGUS[52] has seen the decay $D^0 \to \Phi K_S^0$:



They got (see Fig. 44) : $BR = (1. \pm 0.32 \pm 0.17)\%$

CORNELL[53] (CLEO) measured (preliminary) the inclusive $B \to \Phi + X$ rate . (Fig. 45)

The inclusive result is : $BR = (2.3 \pm 0.7 \pm 0.4)\%$

The Φ spectrum is consistent with the 1% ΦK_S^0 ,measured by ARGUS.

These diagrams and other unique graphs may eventually explain the D^0 shorter life–time.

Acknowledgements .

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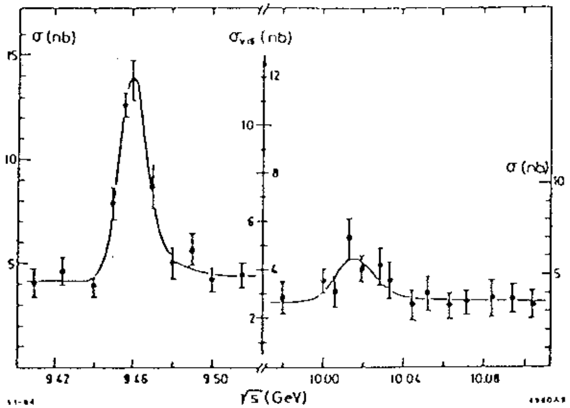
Pseudo − Scalar Mesons		
Quantum nb.	D	F
Charm	$+1$	$+1$
Isospin	$\frac{1}{2}$	0
Strangness	0	1
quarks	$c\bar{d}, c\bar{u}$	$c\bar{s}$
Charge	D^+, D^0	F^+
Mass (Mev)	1869, 1865	1975

Vector Mesons		
Quantum nb.	D^*	F^*
Charm	$+1$	$+1$
Isospin	$\frac{1}{2}$	1
Strangness	0	1
quarks	$c\bar{d}, c\bar{u}$	$c\bar{s}$
Charge	D^{*+}, D^{*0}	F^{*+}
Mass (Mev)	2010, 2007	2109

Fig. 1.
Quantum numbers and masses of Charmed mesons.



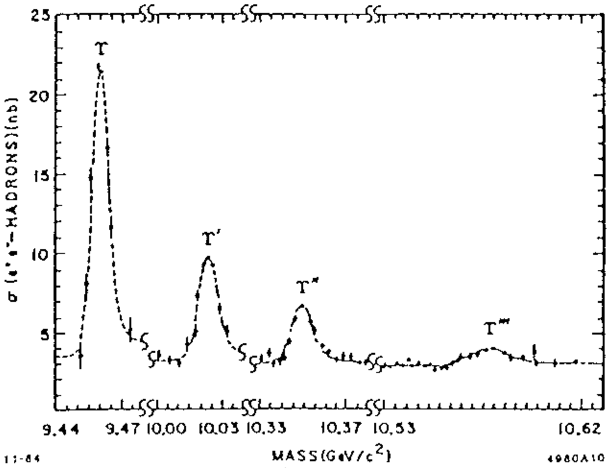


Fig. 2.
First observation of Υ in DESY and CORNELL.

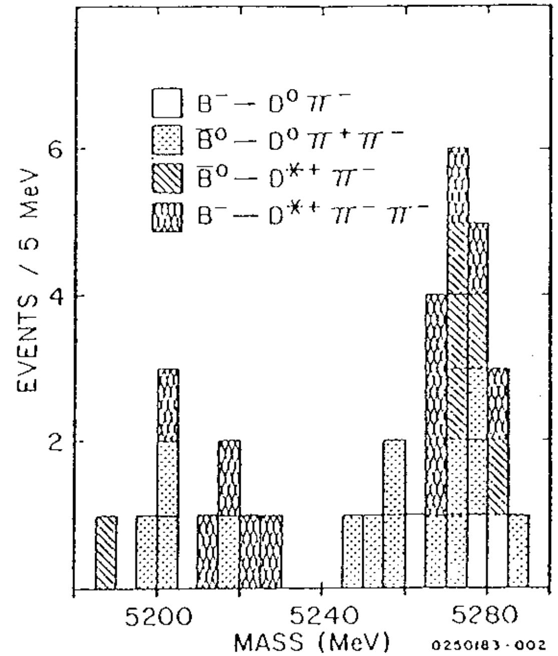


Fig. 3.
First observation of B-mesons.

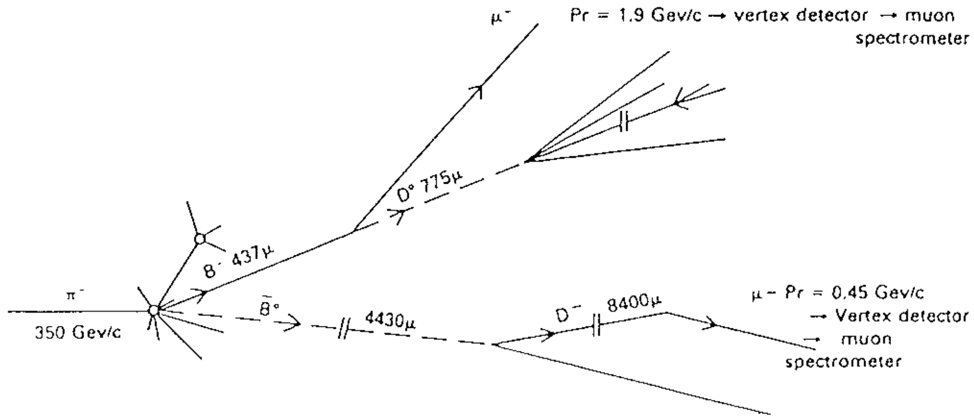


Fig. 4.
Example of B seen[6] in WA75.

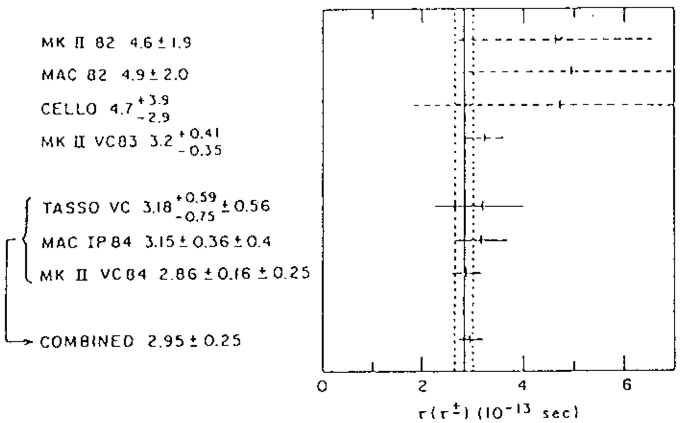


Fig. 5.
Compilation of recent τ lepton life-times.

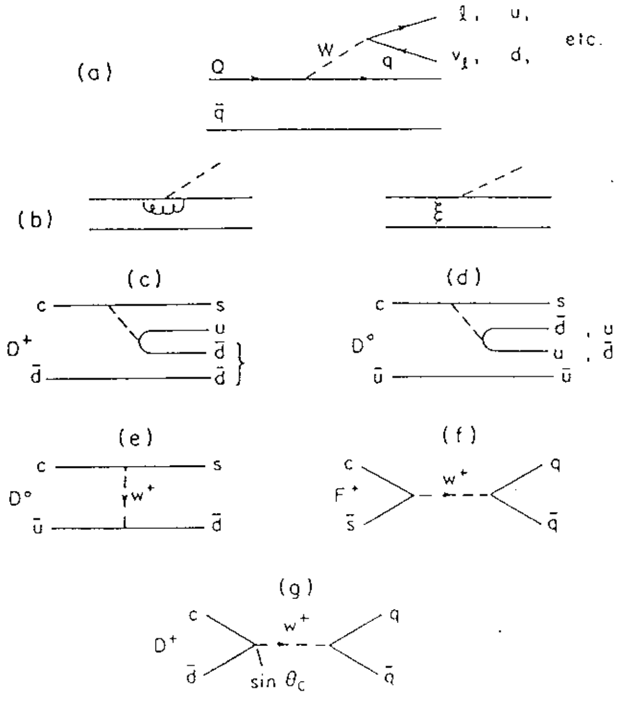


Fig. 6.
The main graphs leading to charm meson decays.

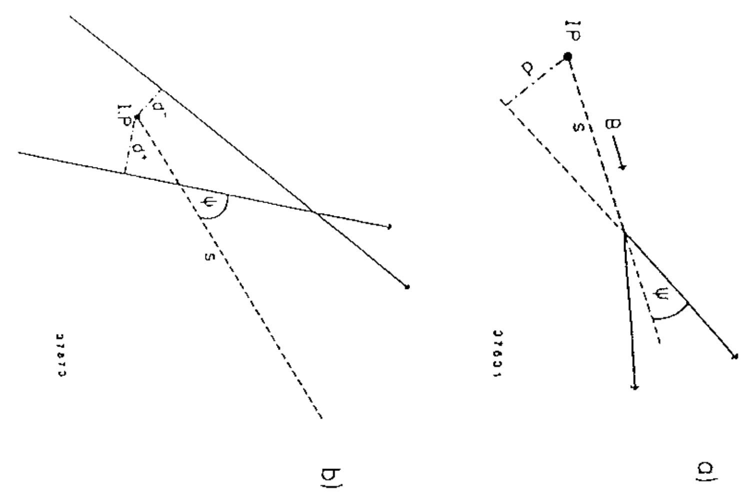


Fig. 7.
Definitions of impact parameters : S is sphericity axis
B is direction of B meson and (a) true B decay tracks
(b) background tracks.

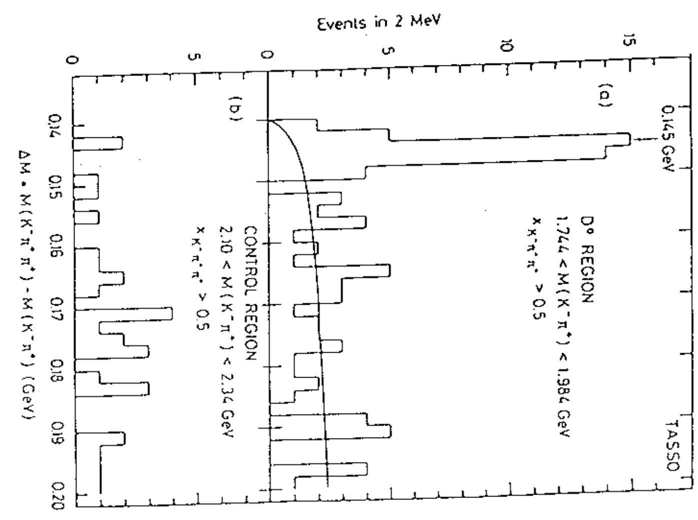


Fig. 8.
Distribution[11] of $\delta M = M(K^-\pi^+\pi^+) - M(K^-\pi^+)$, and c.c.,
at $Z > 0.5$, for (a) the D^0 region and (b) control region. (PETRA).

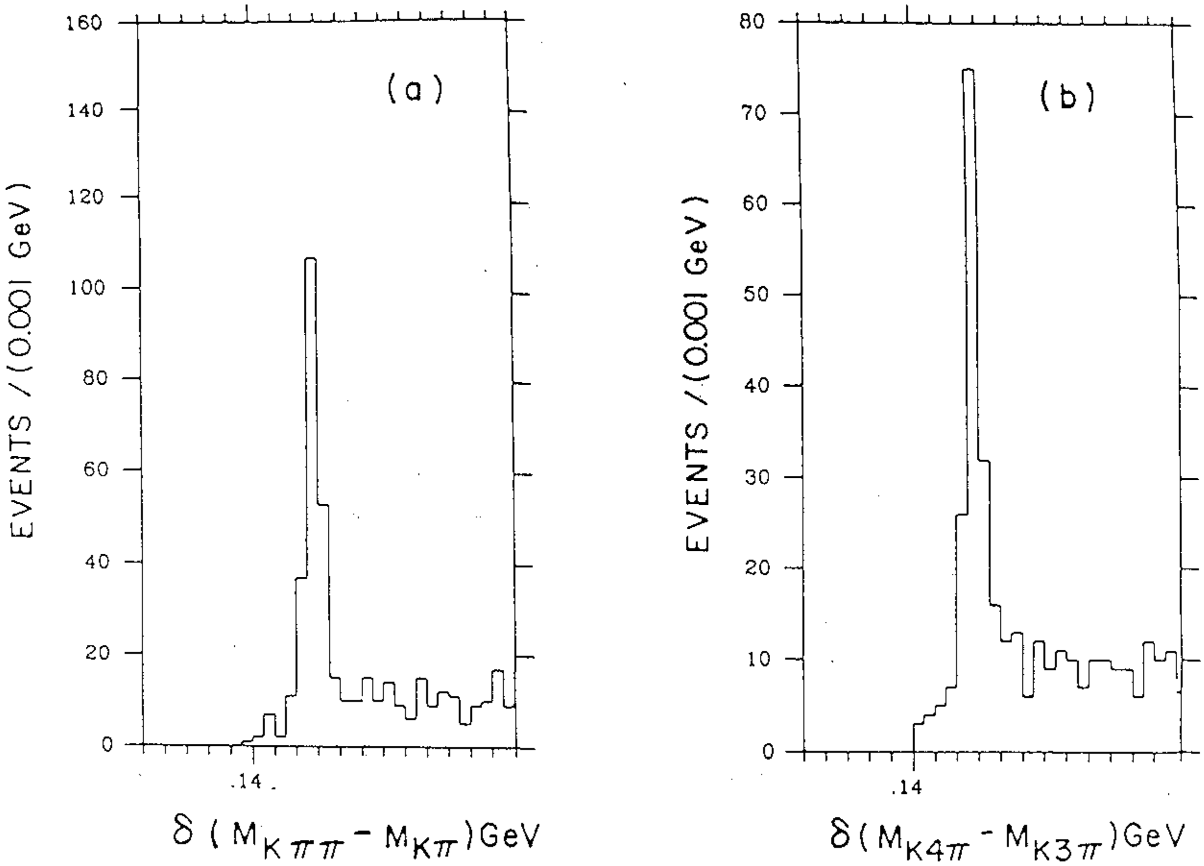


Fig. 9.
Distribution[12] of $\delta M = M(D^{*+} \to D^0\pi^+) - M(D^0)$ for
(a) $D^0 \to K\pi$ and (b) $D^0 \to K3\pi$.
$M(D^0)=(1.81\text{-}1.92)$ GeV/c and $Z(D^0)\geq 0.4$ (HRS,PEP).

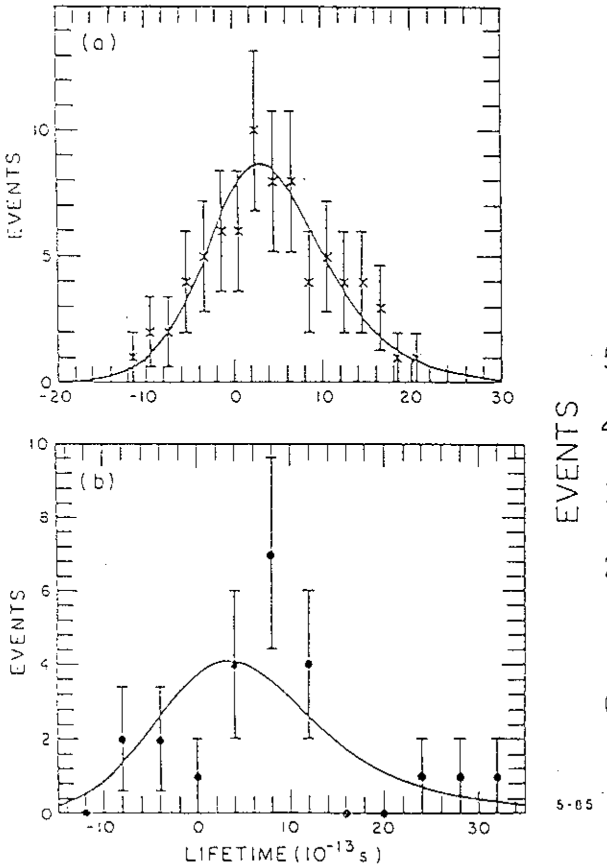


Fig. 10.
Life-time distributions (MARK II[12]) for
(a) $D^0 \to K\pi + K\pi\pi$ and (b) D^+ decays.
The curves are the result of a maximum likelihood fit to the data.

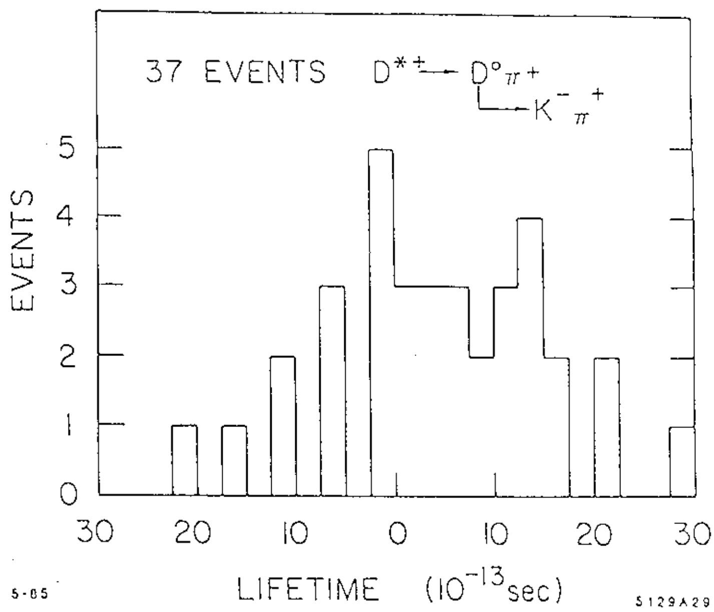


Fig. 11.
Recent D^0 life-time distributions from HRS[12].

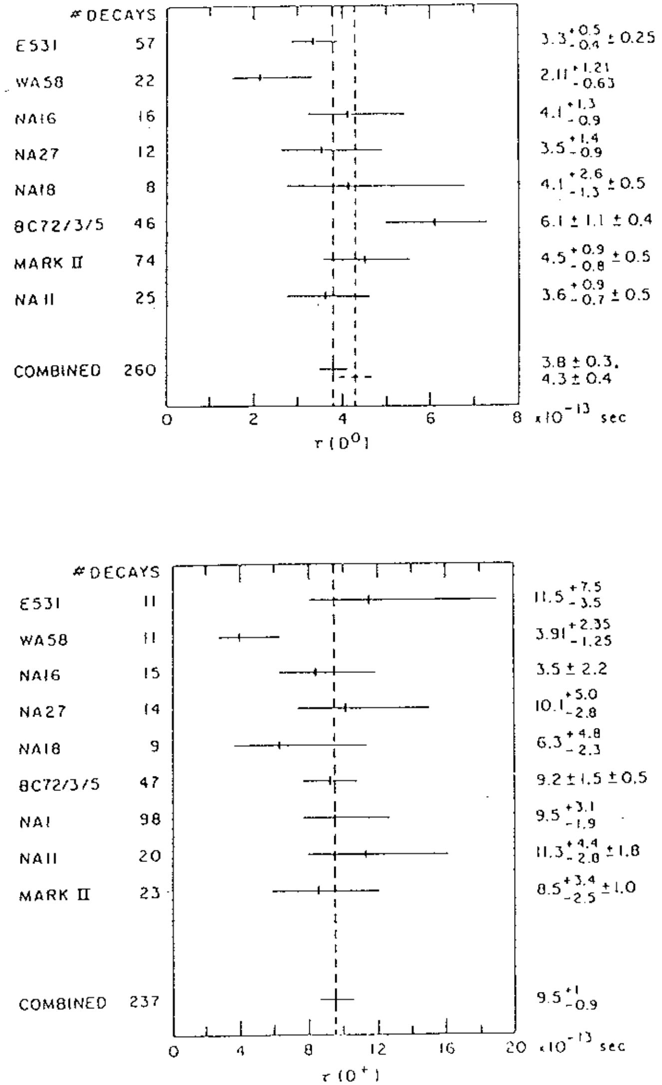


Fig. 12.
Compilation of D^0 and D^+ life-times (1985).

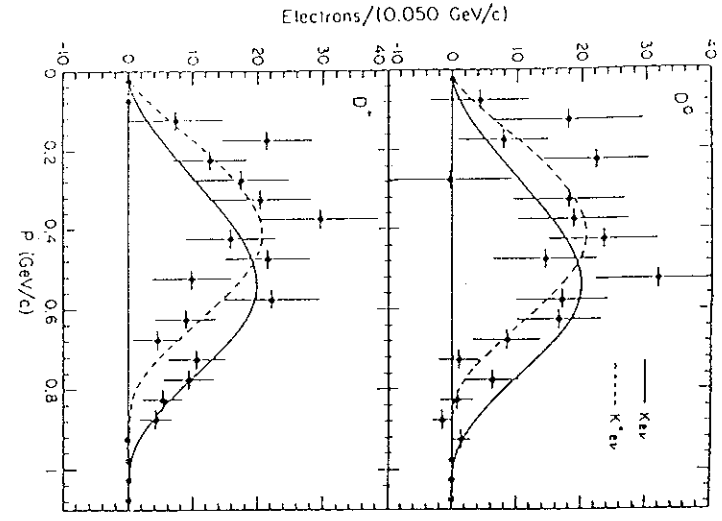


Fig. 13.
Electron spectra (MARK III[14]) seen in
(a) D^0 decays and (b) D^+ decays.

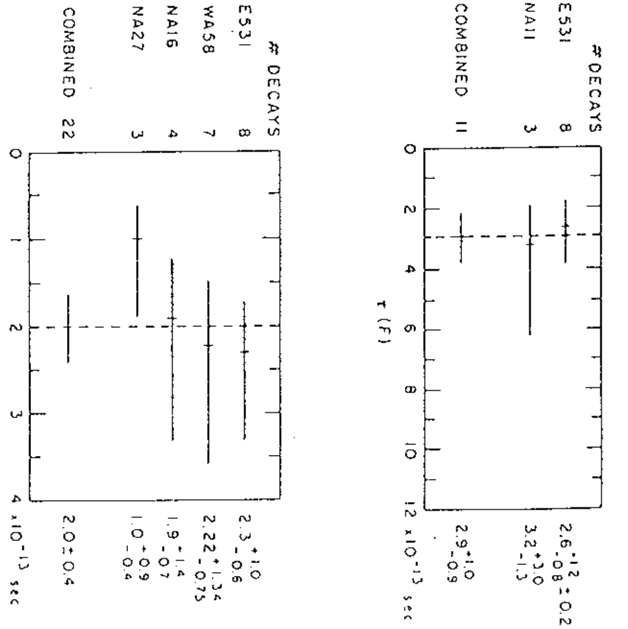


Fig. 14.
Compilation[13] of $F^\pm$ and Λ_c life-times.

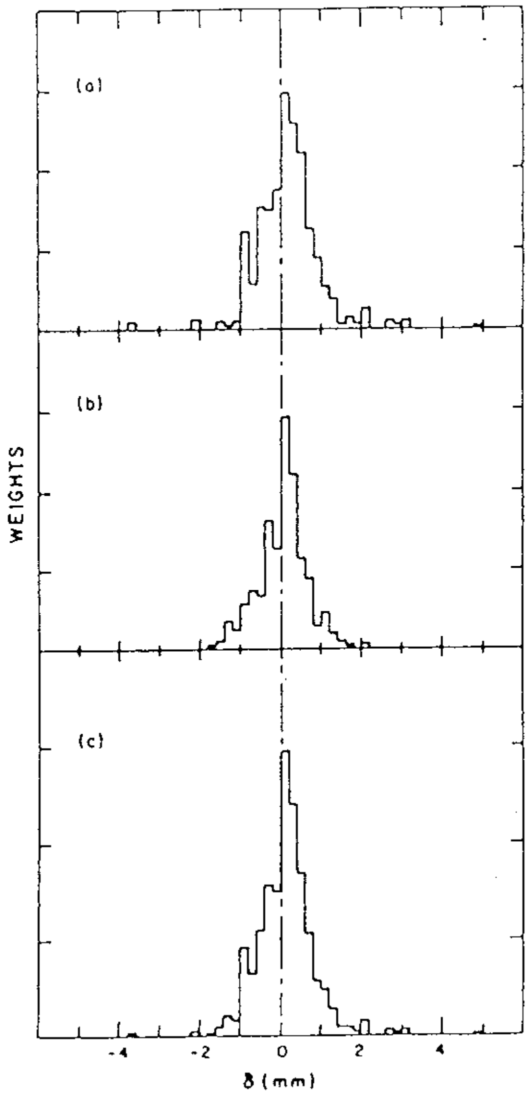


Fig. 15.
Impact parameter distribution[15] of Leptons from b-decay. (MAC'84)
(a) muons (b) electrons (c) all leptons.

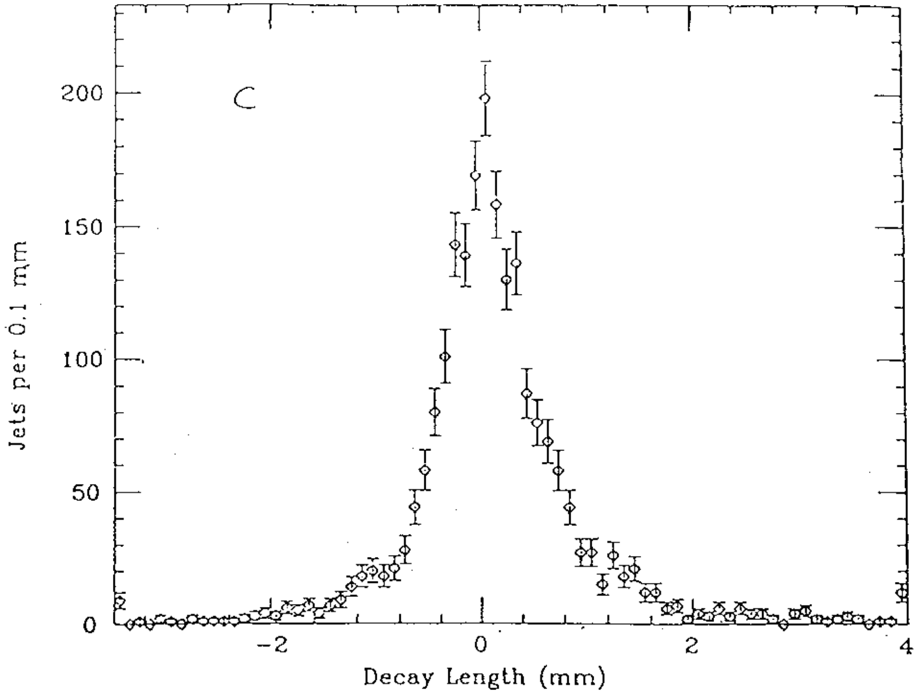


Fig. 16.
Decay length distribution of secondary vertex,
b-enriched sample. (MARK II[16])

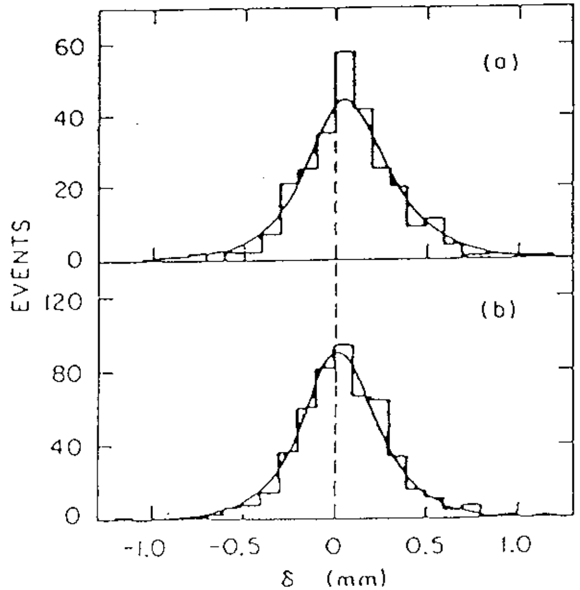


Fig. 17.
Impact parameter distribution of leptons in the
(a) b-enriched and (b) c-enriched samples. (MARK II[16])

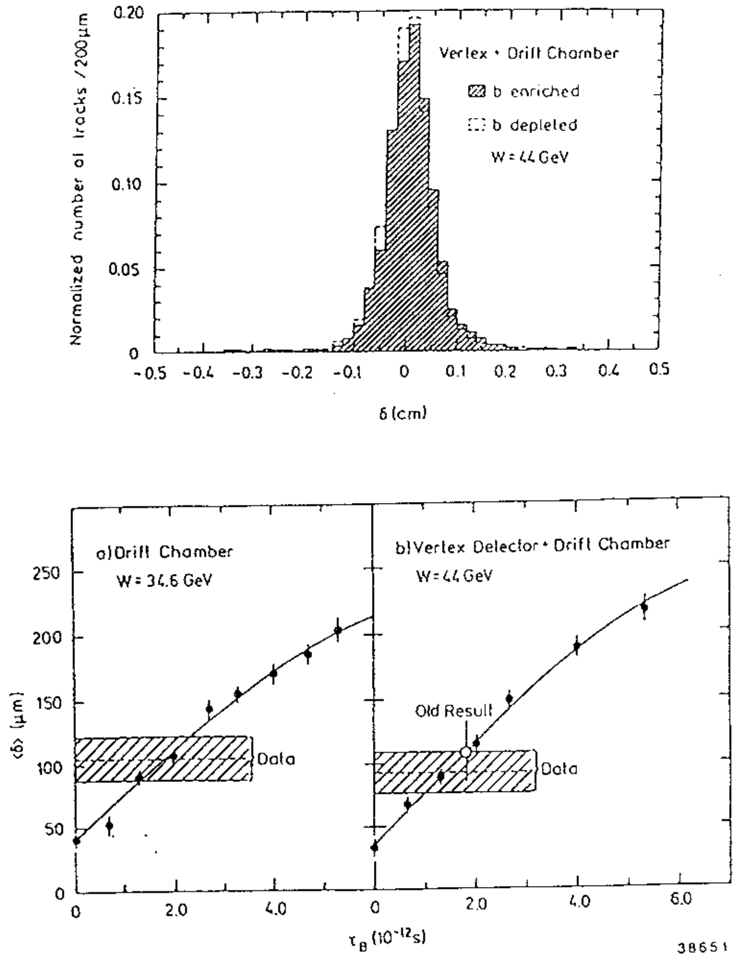


Fig. 18.
Impact parameter distribution (TASSO'85) of all hadronic events[17] in b–enriched and b–depleted samples. b life–time determination in (a) Drift chamber data and (b) Vertex detector data. The curves are the results of M.C. calculations.

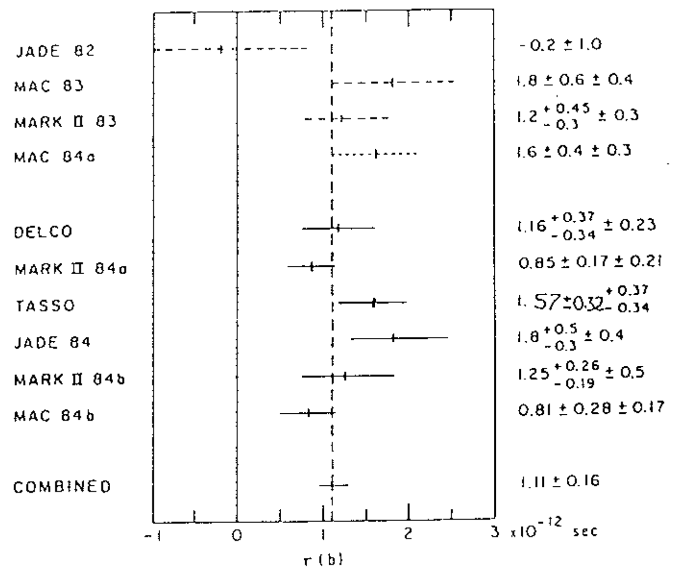
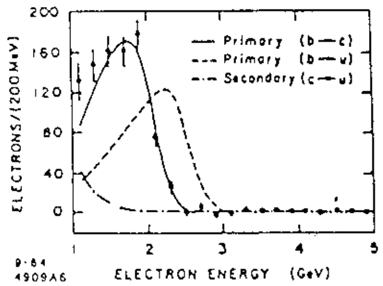


Fig. 19.
Compilation[13] of all recent b life-times.



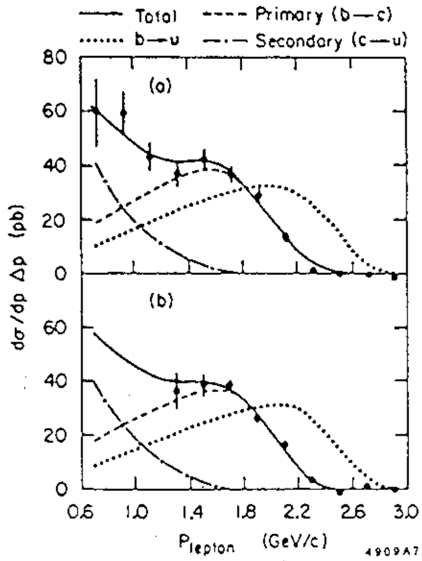


Fig. 21.
Semi-leptonic b decays from CUSB[25] (electrons)
and CLEO[24] (a) electrons (b) muons
Also shown the calculated primary processes (b → c , b → u)
and secondary processes (b → c → u) spectra.

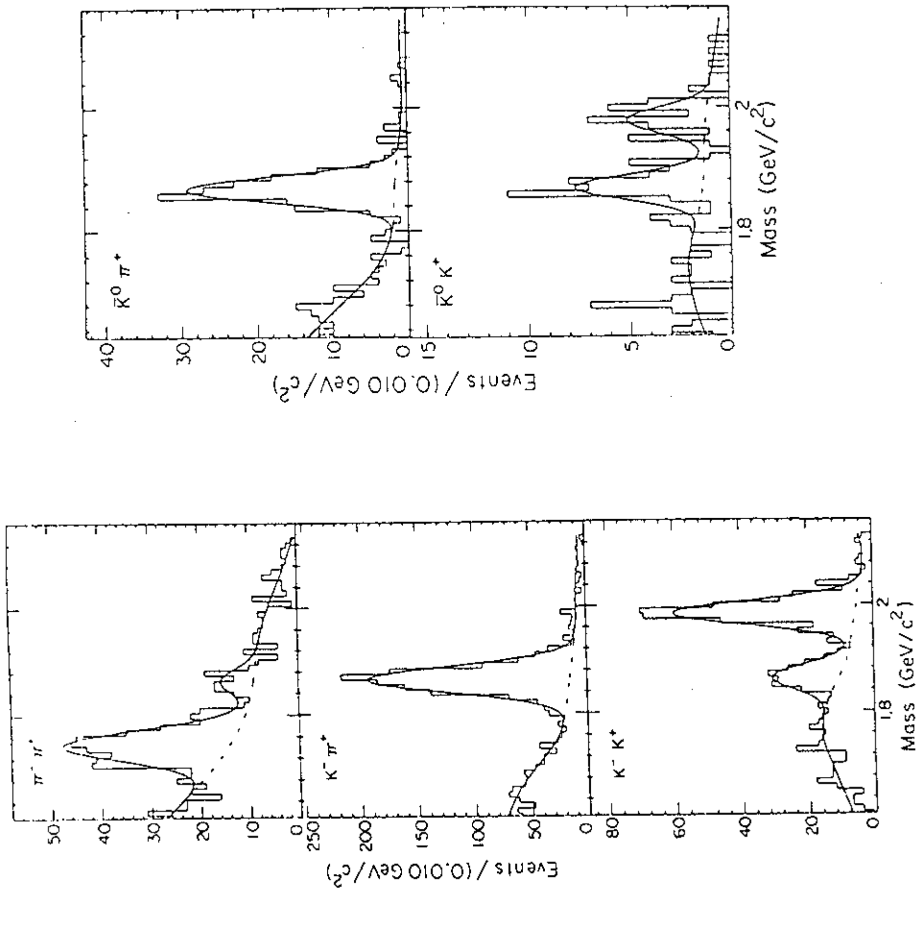


Fig. 20.
Cabbibo suppressed hadronic D^0 and D^+ decays.
For comparison also shown are allowed decays ($K^- \pi^+$ and $\bar{K}^0 \pi^+$)
(MARK III[20], 1985).

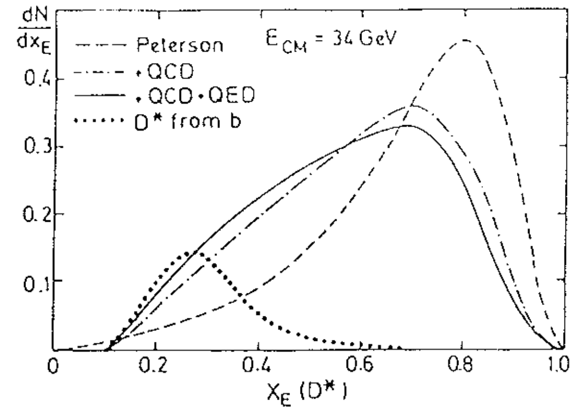


Fig. 22.
Example of the expected D^* fragmentation function from the Peterson model and the effect of various corrections[31] on it .

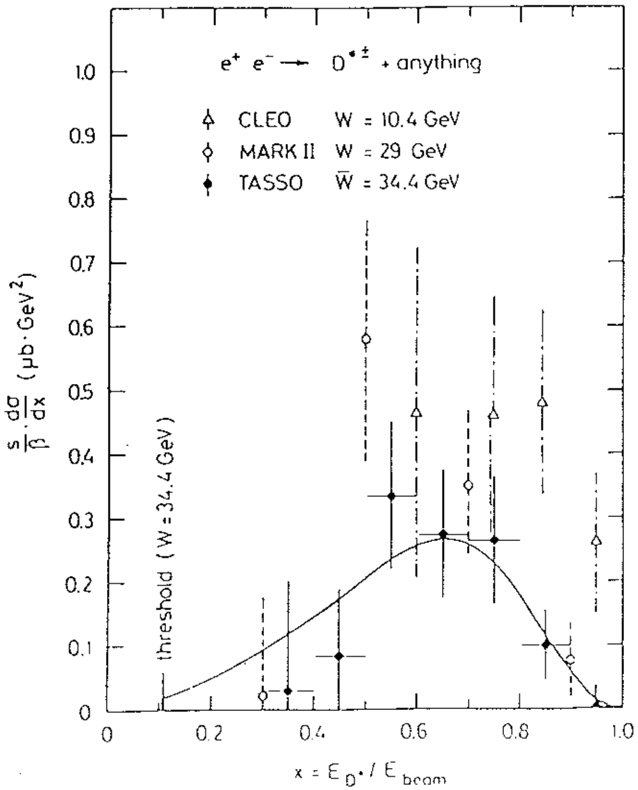


Fig. 23.
Example of the observed D^* invariant cross-section, older result[32].

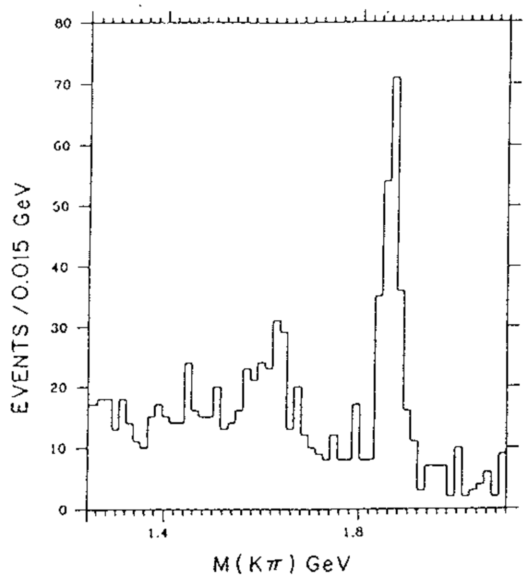


Fig. 24.
Recent HRS results[33] (1985) : M(K π) for δ = 0.143 – 0.149 GeV.

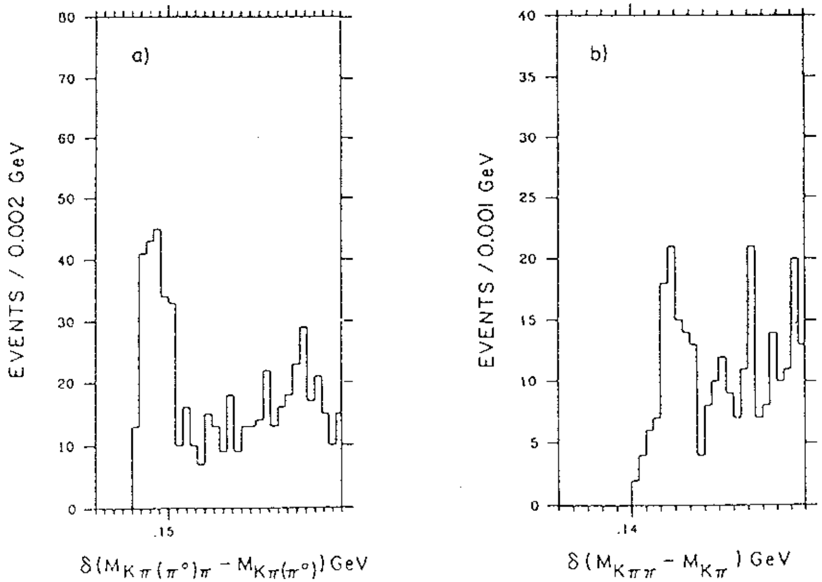


Fig. 25.
Recent HRS results[33] (1985) : δ = $M(D^{*+}) - M(D^0)$
for (a) $Z \geq 0.4$ and (b) $Z = 0.2 - 0.4$,
M(K π) = 1.55 – 1.70 GeV/c.

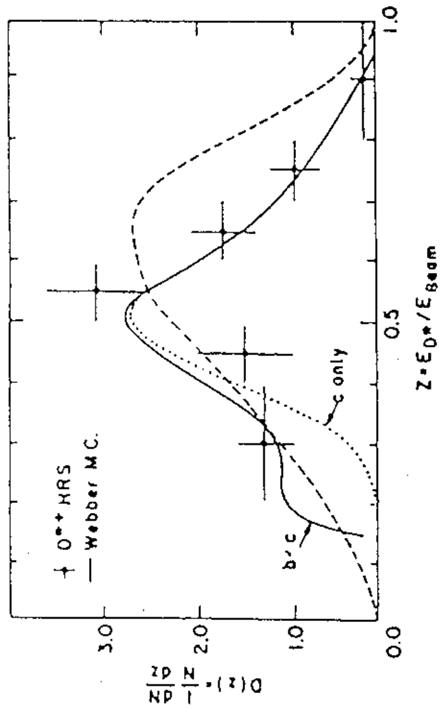


Fig. 28.
Invariant cross-section for D* production, HRS.

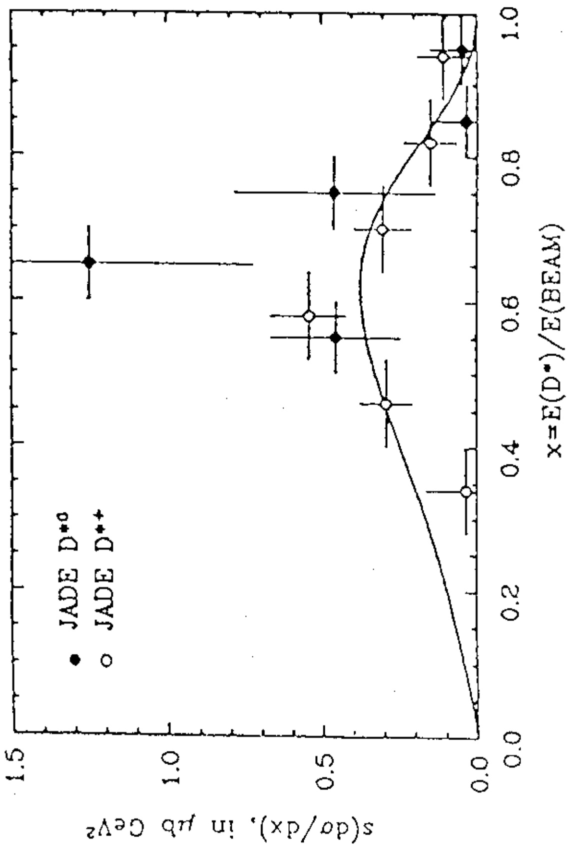


Fig. 29.
Invariant cross-section for D* production. JADE.

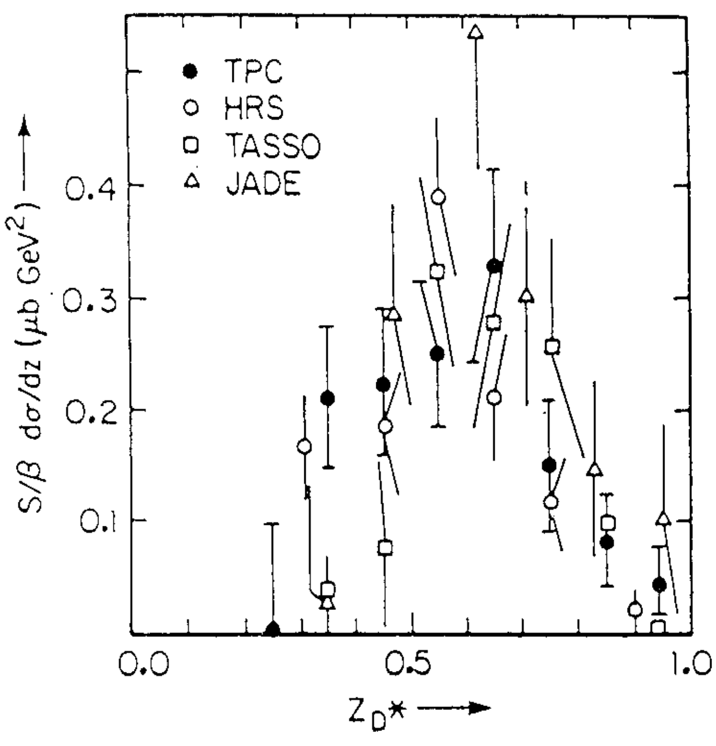


Fig. 26.
Invariant cross-section for D*± production, TPC/PEP-4.

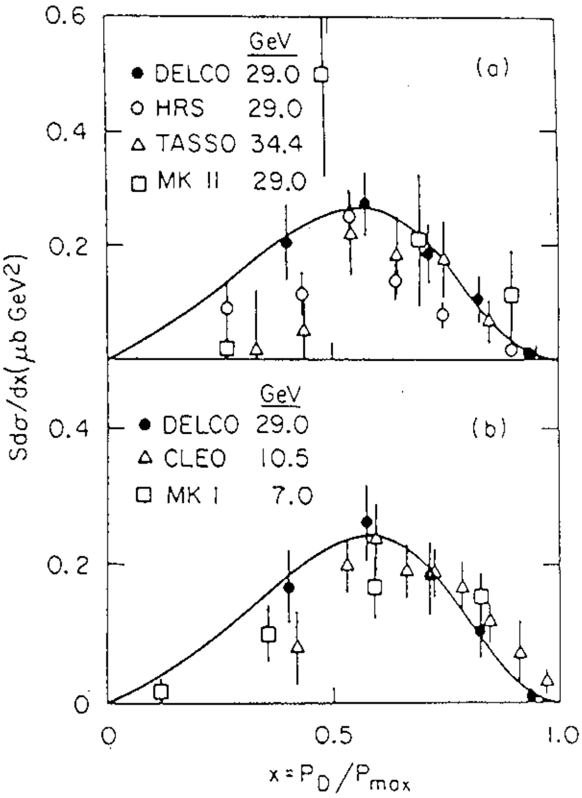


Fig. 27.
Invariant cross-section for D⁰ production, DELCO.

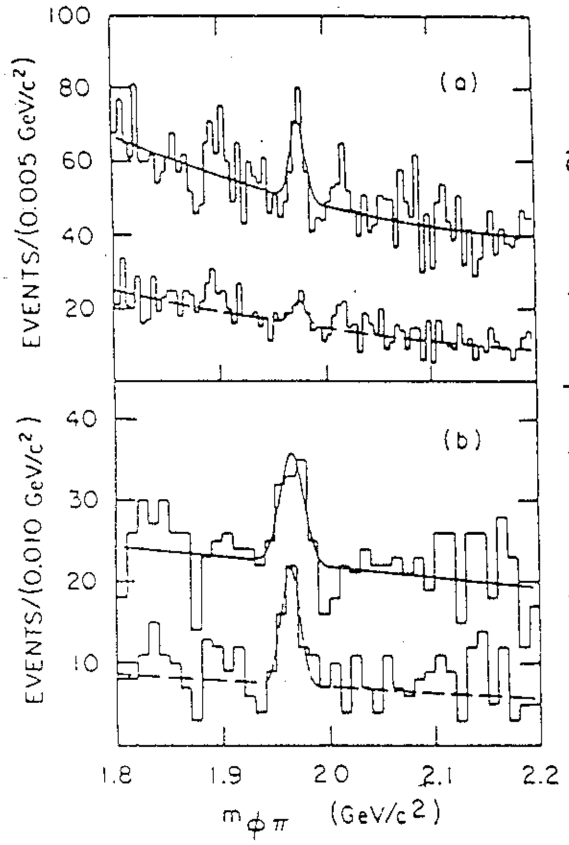


Fig. 30.
Latest $F \to \phi\pi$ observations from HRS[39]:
(a) $Z = .2 - .4$ and (b) $Z \geq .4$
Also shown (*lower histograms*) the mass plots in angular cuts enhancing 0^- meson decays.

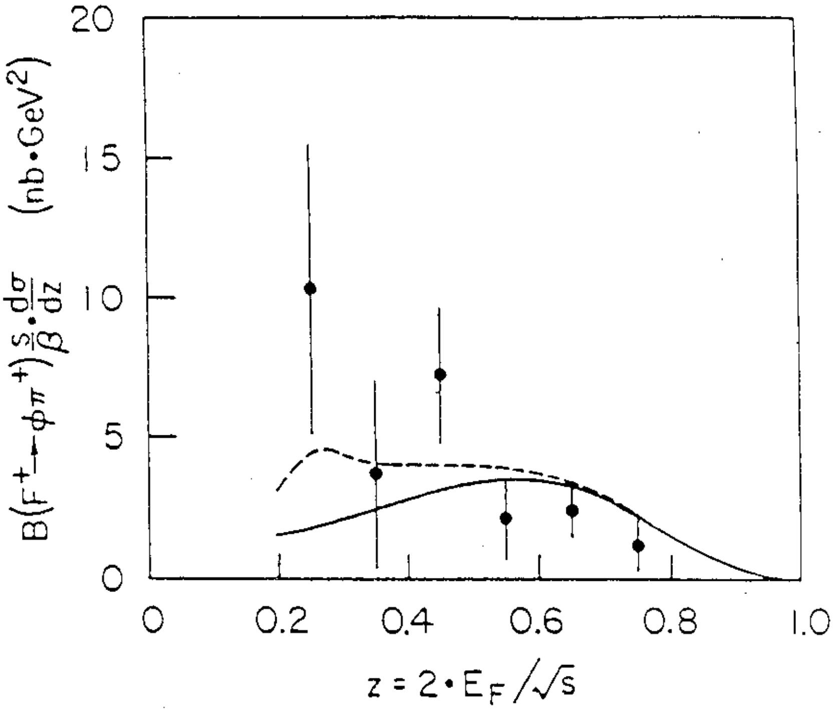


Fig. 31.
The F fragmentation function observed by HRS[39]:
the solid line indicates the D^* fragmentation for $z > .4$ data,
and the broken line the sum of expected contributions
from direct c quarks and $b \to c$.

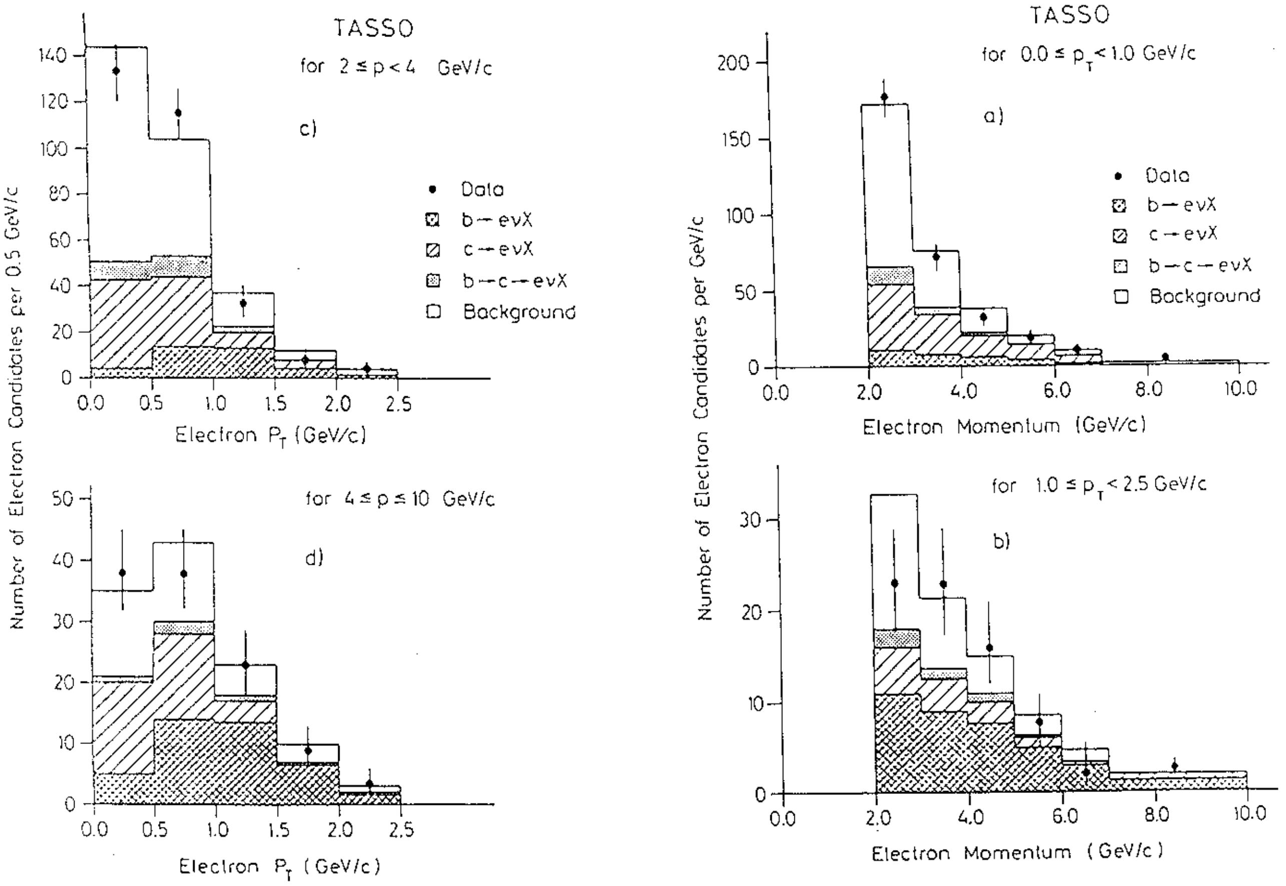


Fig. 32.
New electron inclusive spectra from TASSO[41] for various p_T intervals,
(a)-(d), as indicated in the figure. The shaded areas in each graph correspond to
the various contributing processes and are obtained from overall fits to M.C.
spectra.

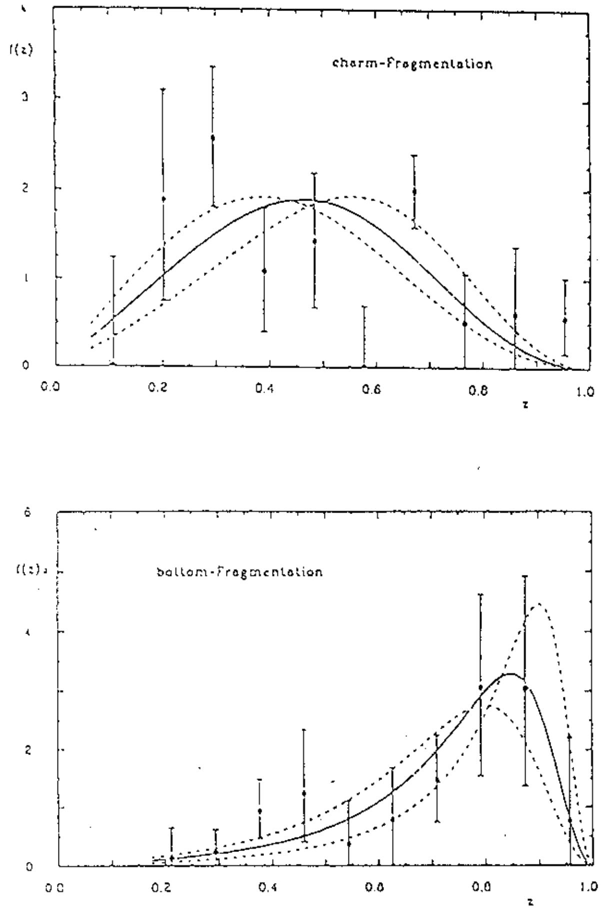


Fig. 34.
The fragmentation functions obtained by MARK J[42] as function of Z. F(Z) is gotten from a fit at each Z-bin. The smooth line corresponds to the parameters given in the text and the dashed curves indicate the statistical and systematic errors limits.

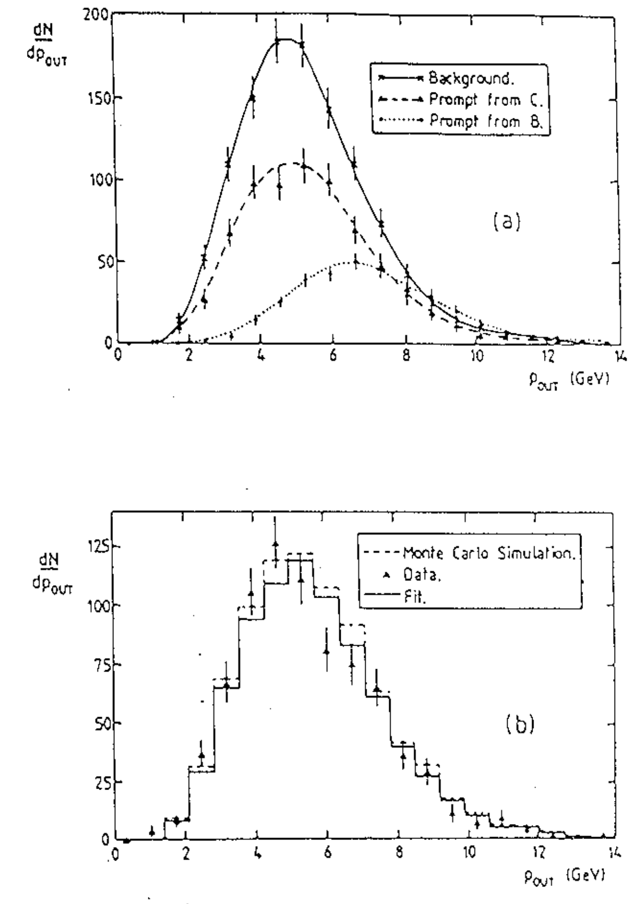


Fig. 35.
The new JADE[43] results of inclusive muons distributions: P_{out} variable
(a) M.C. distributions for the various contributing processes.
(b) Data, M.C. and the fit results of the data to b and c decays.

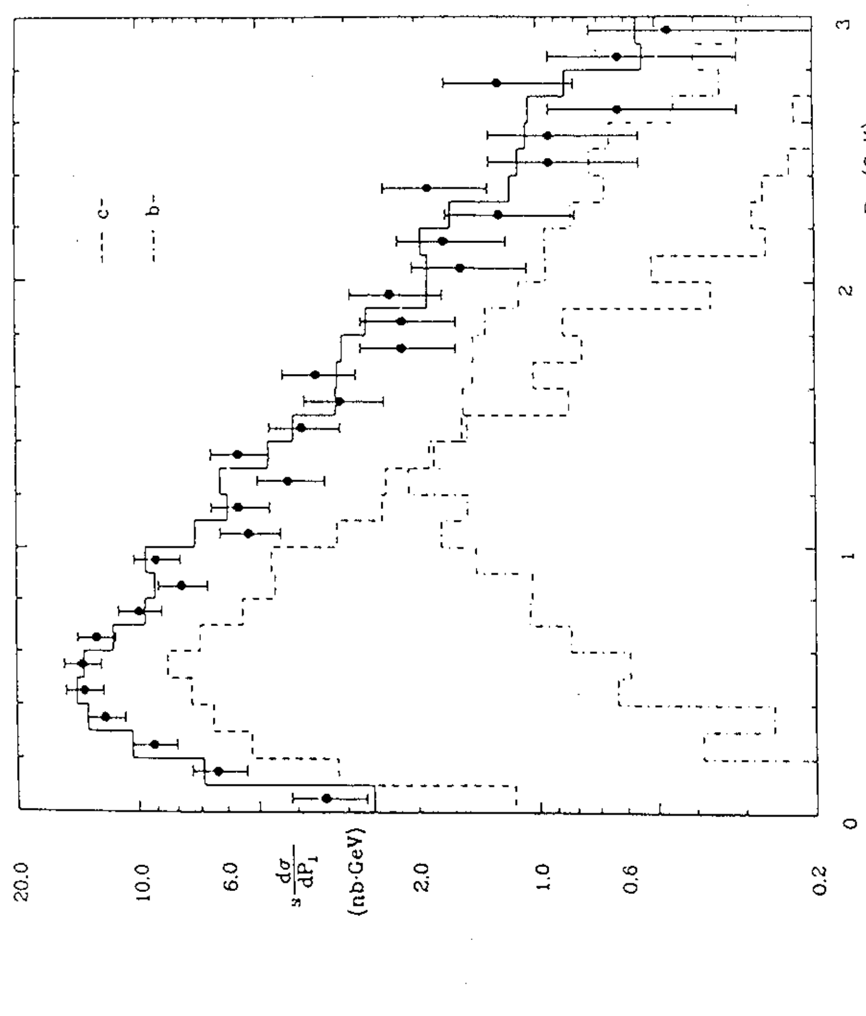


Fig. 33.
New muon inclusive spectra from MARK J[42] as function of p_T, relative to the T-axis. The histograms indicate the contribution of the various processes and the sum histogram (*solid line*) includes also the background.

Charm Fragmentation Function

Experiment		Variable	Mean	ϵ_c
MARK J	μ	z	$0.46 \pm 0.02 \pm 0.05$	$0.8 \pm 0.1 \pm 0.2 = \sqrt{\epsilon_c}$
TASSO	μ	z	$0.77 \pm^{[illegible]}_{0.07} \pm^{0.01}_{0.11}$	$0.006 \pm^{0.017}_{0.005} \pm^{0.032}_{0.003}$
	μ	x	$0.71 \pm^{0.03}_{0.07} \pm^{0.04}_{0.11}$	
	e	z	$0.57 \pm^{0.10}_{0.09} \pm^{0.03}_{0.04}$	$0.24 \pm^{0.35}_{0.16} \pm^{0.17}_{0.08}$
DELCO	e	x+Y	0.69 ± 0.06	$0.05 \pm^{0.06}_{0.03}$
	e	x	0.66 ± 0.06	$0.071 \pm^{0.026}_{0.038}$
TPC	e	x+Y	$0.55 \pm 0.07 \pm 0.03$	$0.26 \pm^{0.24}_{0.13} \pm^{0.09}_{0.04}$
AVERAGE	e,μ		0.5 - 0.7	
JADE	D^*	x	0.64 ± 0.05	0.24 0.08
TASSO	D^*	x	0.59 ± 0.04	$0.25 \pm^{0.13}_{0.08}$
HRS	D^*, D^0	x	0.53 ± 0.03 (D^*)	$0.35 \pm^{0.07}_{0.06}$ (D^*, D^0)
MARK II	D^*	x	0.58 ± 0.06	~0.25
TPC -	D^*	x+Y	$0.58 \pm 0.03 \pm 0.05$	0.28 ± 0.11 (preliminary)
AVERAGE		x	0.57 ± 0.02	0.30 ± 0.04
CDHS	ν	x	$0.68 \pm 0.05 \pm 0.06$	
E531	ν	x	$0.59 \pm 0.03 \pm 0.03$	
AVERAGE		x	0.61 ± 0.04	

Bottom Fragmentation Function

Experiment		Variable	Mean	ϵ_b
MARK J	μ	z	$0.75 \pm 0.03 \pm 0.06$	$0.15 \pm 0.03 \pm 0.05 = \sqrt{\epsilon_b}$
TASSO	μ	z	$0.85 \pm^{0.10}_{0.12} \pm^{0.02}_{0.07}$	$0.0025 \pm^{0.029}_{0.0025} \pm^{0.011}_{0.0013}$
	μ	x	$0.81 \pm^{0.04}_{0.09} \pm^{0.02}_{0.05}$	
	e	z	$0.84 \pm^{0.15}_{0.10} \pm^{0.13}_{0.11}$	$0.005 \pm^{0.022}_{0.005} \pm^{0.020}_{0.005}$
DELCO	e	x+Y	0.78 ± 0.05	$0.018 \pm^{0.024}_{0.011}$
		x	0.76 ± 0.06	$0.025 \pm^{0.034}_{0.015}$
MAC	μ	z	0.8 ± 0.1	$0.008 \pm^{0.037}_{0.008}$
MARK II	μ	z	$0.73 \pm 0.15 \pm 0.10$	$0.042 \pm^{0.218}_{0.008} \pm^{0.12}_{0.035}$
	e	z	$0.79 \pm 0.06 \pm 0.06$	$0.015 \pm^{0.022}_{0.011} \pm^{0.023}_{0.011}$
TPC	μ	x+Y	$0.83 \pm 0.05 \pm 0.03$	$0.0065 \pm^{0.0096}_{0.0041} \pm^{[illegible]}_{[illegible]}$
	e	x+Y	$0.74 \pm 0.05 \pm 0.03$	$0.033 \pm^{0.037}_{0.019} \pm^{0.019}_{0.012}$
AVERAGE		x	0.80 ± 0.03	

Fig. 36.
A summary table of c and b fragmentation functions .

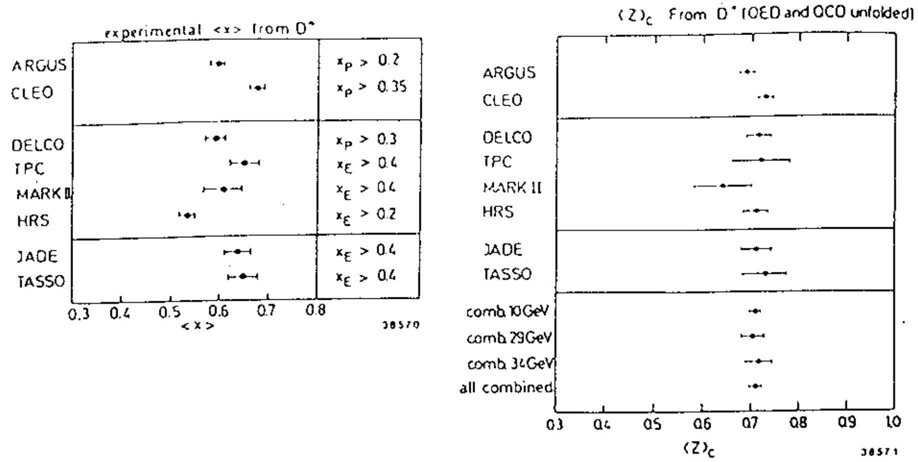


Fig. 37.
The raw and corrected values of $< Z >_c$ as calculated in ref. 31 .

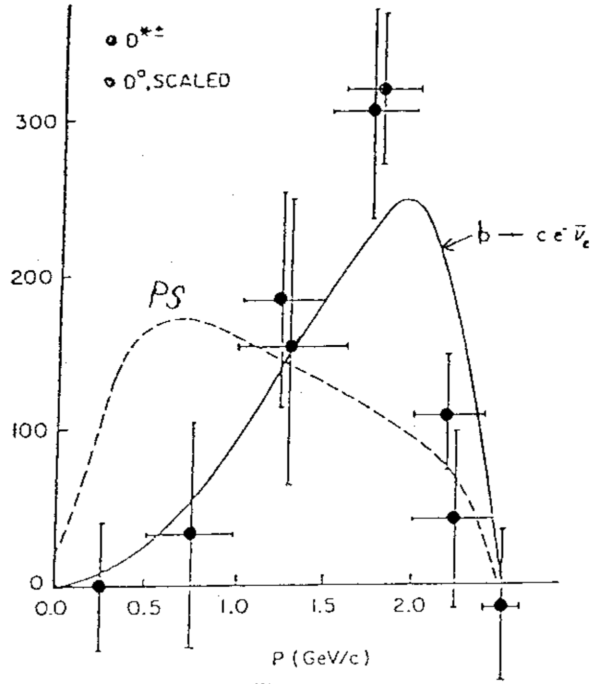


Fig. 38.
Momentum distribution of $D^*(D^0)$ obtain for the direct semi-leptonic decay $B \to D^{*}(D^0) e \nu_e$ as observed by CLEO[44].
The solid curve shows the expected distribution for a (V-A) B hadron decay and the dashed curve is phase-space. (the ordinate is no. D^* / GeV/c).

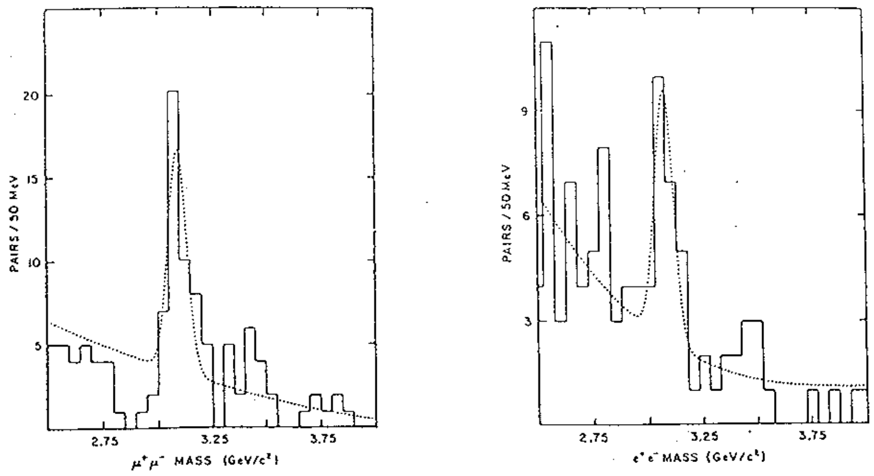


Fig. 39.
The color-suppressed decay $B \to J/\Psi + X$ as seen by CLEO[45] : both $\mu^+\mu^-$ and e^+e^- decays.

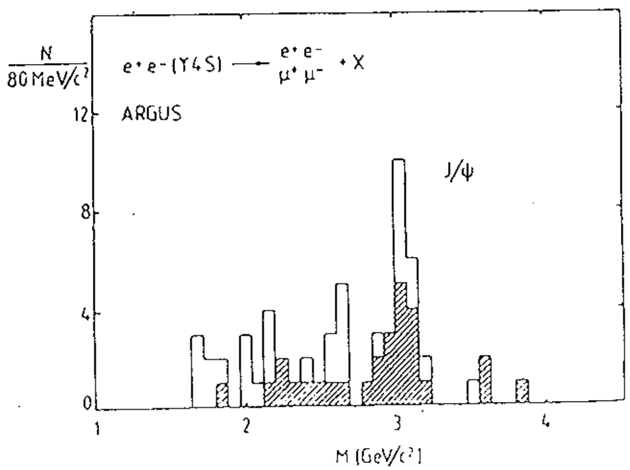


Fig. 40.
The color-suppressed decay $B \to J/\Psi$ as seen by ARGUS[46] .

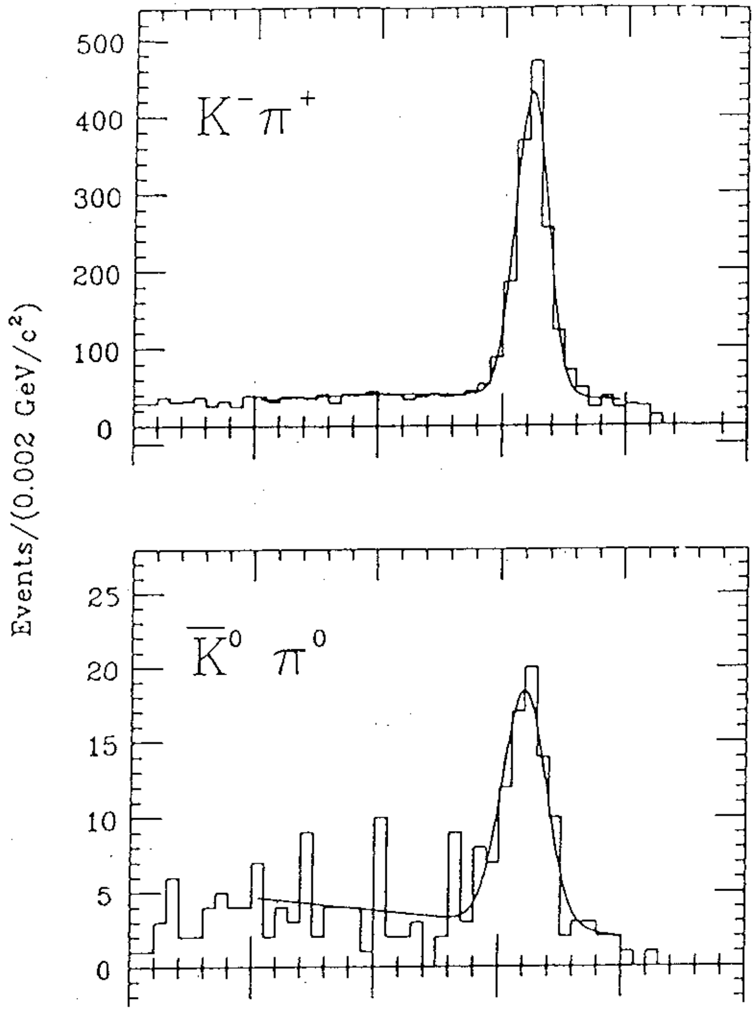


Fig. 41.
The color-allowed ($K^+\pi^-$) and the color-suppressed ($\overline{K^0}\pi^0$) D^0-decays into final state of light quarks as seen by MARK III[48] .

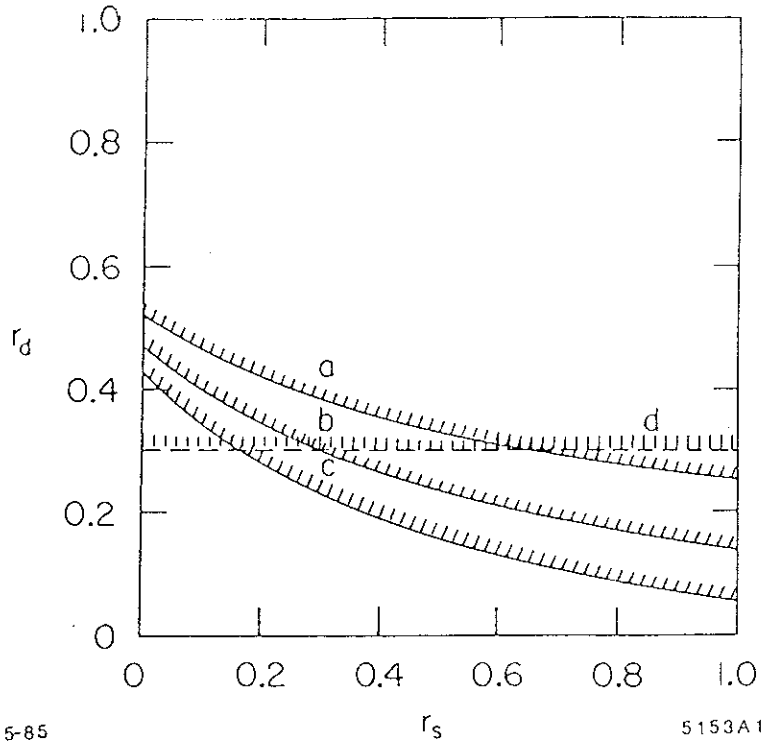


Fig. 42.
Limits on the $B_d^0 - \overline{B_d^0}$ and $B_s^0 - \overline{B_s^0}$ mixing expressed in terms of $r = \Gamma(B^0 \to \ell^- + X)/\Gamma(B^0 \to \ell^+ + X)$, from MARK II[49].
(shaded areas are excluded)
(see ref. 49 for details of the various curves).

Kinematic Regions	Opp. Jet Opp. Sign	Opp. Jet Same Sign	Same Jet Opp. Sign	Same Jet Same Sign
both *b*-enriched	10 (10.0 ± 2.0)	4 (2.5 ± 0.7)	4 (2.5 ± 0.8)	0 (0.5 ± 0.1)
b-enriched & *c*-enriched	17 (16.8 ± 5.3)	3 (5.9 ± 1.5)	5 (5.5 ± 1.5)	0 (2.3 ± 0.6)
both *c*-enriched	13 (11.8 ± 3.2)	2 (4.2 ± 1.0)	4 (3.7 ± 0.9)	2 (2.4 ± 0.6)
Total	40 (38.6 ± 10.3)	9 (12.6 ± 3.2)	13 (11.7 ± 3.1)	2 (5.2 ± 1.3)

Fig. 43.
Summary table of expected dilepton events assuming no $B^0 - \overline{B}^0$ mixing, in the various kinematic regions.
The observed numbers are given in brackets. (MARK II experiment[49],1985)

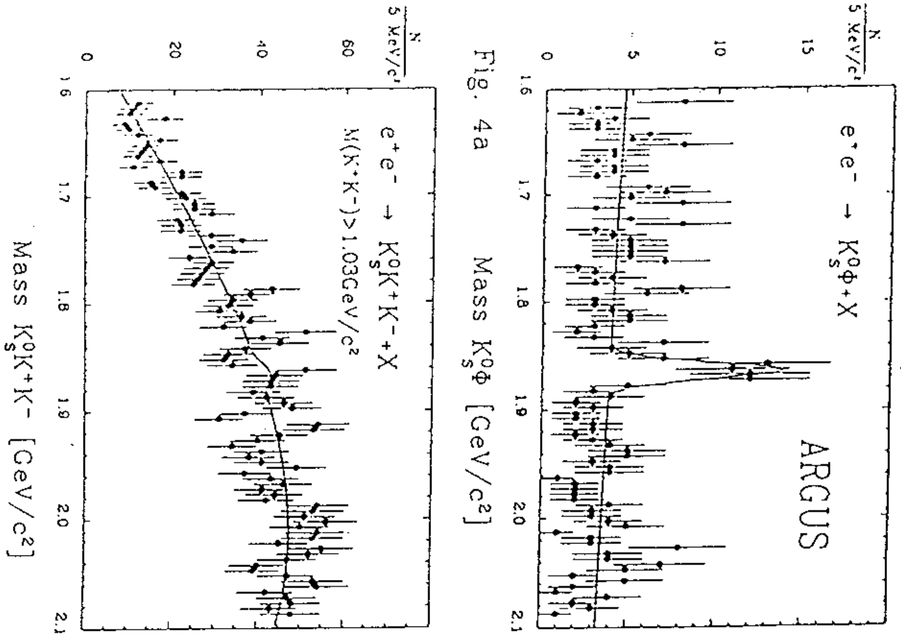


Fig. 44.
Mass plot of $K_S^0\Phi$ and $K_S^0K^+K^-$ (non-Φ) final states, showing the D^0 peak in the $M(K_S^0\Phi)$ plot. (ARGUS[52] 1985).

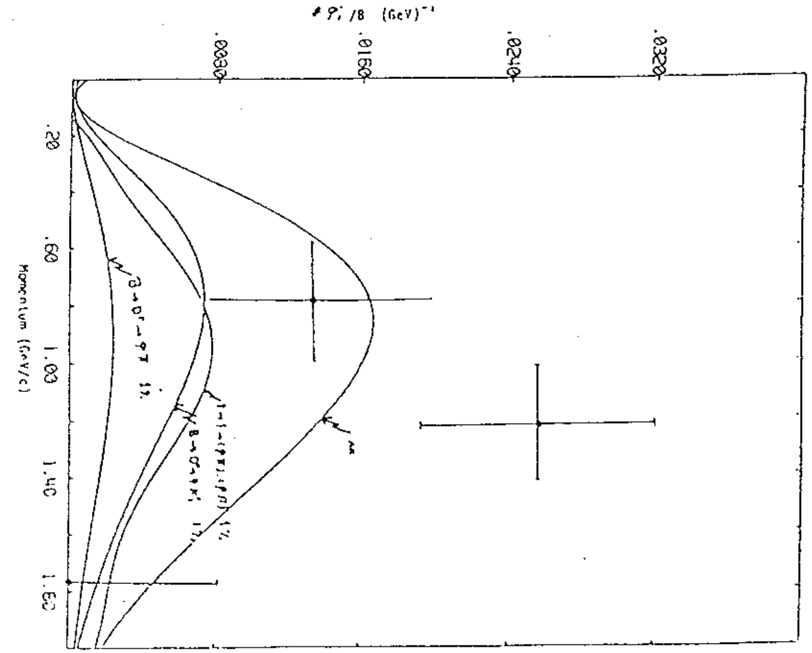


Fig. 45.
Inclusive Φ spectrum measured by CLEO[53].
The contributions of the various sources are indicated by the smooth curves.