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" Measurement of charmed meson lifetimes "

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CHAPTER 1

" Theoretical Interests in Weak Decays of Charmed Mesons "

(A) General Remarks

The lowest states of charmed mesons (D^0 - 1865 Mev, $D^{\pm}$ - 1868 Mev, $F^{\pm}$ - 2030 Mev) are expected to decay via weak interaction, because strong as well as electromagnetic interactions do not violate flavour quantum numbers.

The theoretical interest in measuring the D and F lifetimes can be roughly summarized as follows :

(i) If their lifetimes are consistent with a weak decay we have a straigth confirmation that they do carry a new quantum number.

(ii) Their lifetimes must be in accord with Weinberg-Salam theory [1] and Glashow-Ilioupoulos-Maiani [2] hypothesis.

(iii) At last, if, as we shall see that D^0 , D^+ and F lifetimes are different, this effect can be explained (or, better, one can attempt to explain it) with the quark-parton model. So details and precious informations on hadronic structure are obtained with the aid of weak interaction.

We introduce now the physical hypothesis on which calculations are perfomed, and then we derive (or in some case we recall) the basic formulae for charmed meson decays.

(B) Hypothesis on weak charmed meson decays.

The main physical hypotesis on which calculations are based are :

(i) The weak interaction theory is the Weinberg-Salam one. Since we are at low energies (respect to the W,Z masses, that are thought to be some tens of Gev) the interaction Hamiltonian is $\frac{G}{\sqrt{2}}\left[J_\mu^+ J^\mu + h.c. \right]$

(ii) The hadronic part of the weak current is written in terms of quarks and it is the one proposed by Glashow-Iliopoulos and Maiani :

$$J_\mu^{hadr} = \bar{c}\, \gamma_\mu (1-\gamma_5)\, s' + \bar{u}\, \gamma_\mu (1-\gamma_5)\, d' , \qquad (1.1)$$

where

$$\begin{aligned} s' &= s \cos\theta - d \sin\theta \\ d' &= d \cos\theta + s \sin\theta \end{aligned}$$

and c,u,d,s are the fields of charmed,up,down and strange quarks, and θ is the Cabibbo angle.

We introduce also a spinor :

$$\psi_0 = c \ , \quad \psi_1 = u \ , \quad \psi_2 = d \ , \quad \psi_3 = s$$

and we can rewrite :

$$J_\mu^{hadr} = \bar{\psi}\, \gamma_\mu (1-\gamma_5) \left(A_0^3 \cos\theta + A_1^2 \cos\theta + A_1^3 \sin\theta - A_0^2 \sin\theta \right) \psi \qquad (1.2)$$

with

$$\left(A^\alpha{}_\beta \right)_{\mu\nu} = \delta^\alpha{}_\mu\, \delta^\beta{}_\nu$$

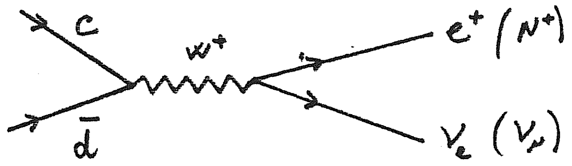
(iii) We assume quark - parton model for hadrons and SU(4) as the symmetry group for strong interactions. In this scheme D^0, D^+, F^+ are the states with c=1 of representation 15 (see FIG[1]).

(iv) The meson states are only quark-antiquark ones. The presence of other states, such as quark+antiquark+gluons, has been taken into account by some authors and it will be shortly discussed .

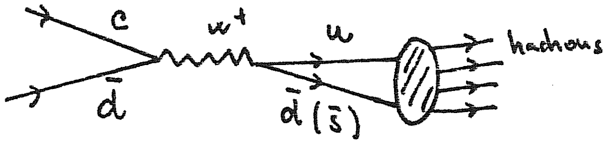
(C) Classification of weak meson decays.

The set of hypothesis we have presented, allows us to describe the charmed meson decays as the decay of the charmed quark into other quarks or quarks and a lepton pair, followed by the rearrangement of the hadronic matter into stable hadrons with probability 1. (This is just the parton model assumption, as - for instance - in deep inelastic phenomena)

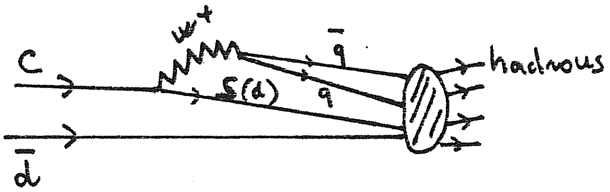
We can write diagrams, at the lowest order in Fermi constant, for these decays :



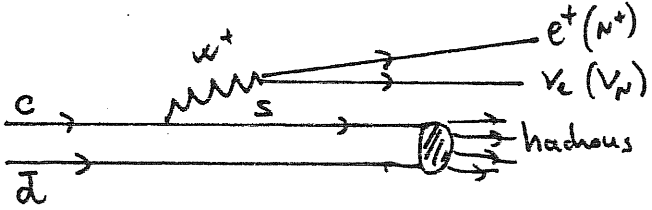
leptonic (1)



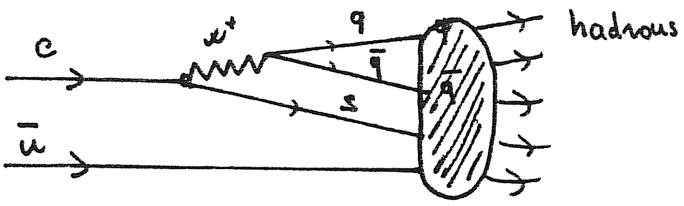
hadronic (2)



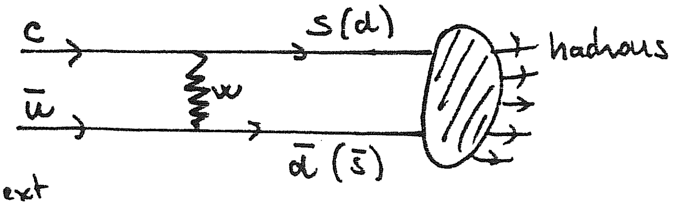
hadronic, too (3)



semileptonic (4)

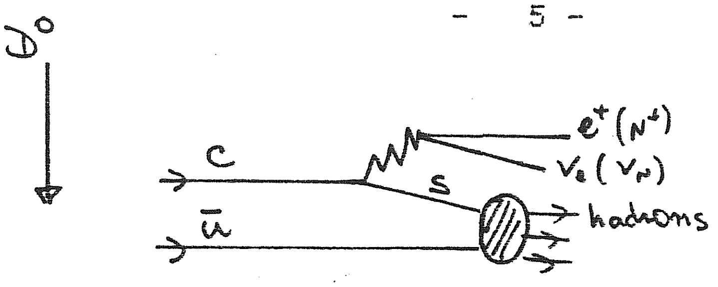


hadronic (5)

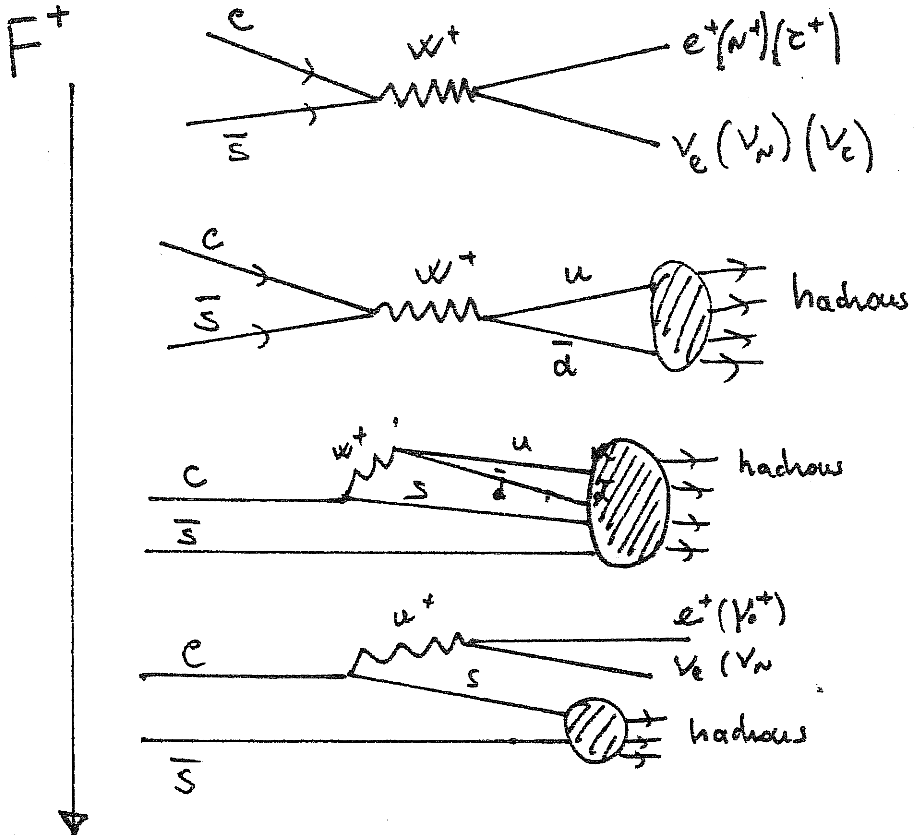


hadronic, too (6)

next



semileptonic (7)



leptonic (8)

hadronic (9)

hadronic, too (10)

semileptonic (11)

Usually, graphs as 1,2,8,9 in which a W is exchanged in the s channel are called annihilation graphs, the 3,4,5,7,10,11 are the "radiation" ones, and as 6 the exchange ones.

We want to illustrate the following statements:

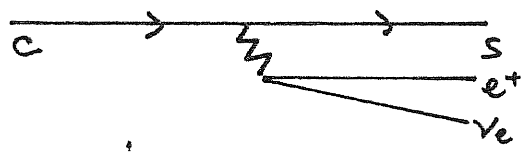
- The semileptonic decay rate is constant for all charmed mesons and this property connects lifetimes and semileptonic branching ratioes.

- Leptonic branching ratioes are negligible, with an exception for F meson. (section 1.E)
- The widths for charmed mesons into hadrons are different and this could be explained with the interference of the diagrams we have given for hadronic decays. This interference can be also treated in an elegant way just considering the SU(4) properties of the weak hamiltonian (section 1.F) .

(D) Semileptonic decays .

The mechanisms of semileptonic decays are illustrated by graphs 4-7-10 . The basic process is the decay of the charmed quark into an s or d quark and in a pair of leptons .

The decay in a strange quark is favoured respect to the "down" one by a factor $\cot^2\theta \cong 20$. So the amplitude for D/F into $E^+ \nu_e$ + hadrons is given by the process :



that is very very similar to the decay diagram for the muon decay . The rate turns out to be, assuming that the mass of s quark is 0 and hat the c mass is 1.65 Gev :

$$\Gamma^{(0)}_{D^+\to e^+X} = \frac{G^2}{192\pi^3} M_c^5 = 4.\,10^{11}\ sec^{-1} \qquad (1.3)$$

It does not depend on the spectator quark, so it is the same for all charmed mesons. Of course the total semileptonic rate is just about twice as much, since also muons can be produced .

Formula (1.3) does not include effects for s mass and for gluon radiation, that, according to the Cabibbo-Maiani calculations, decrease by a factor 3 the width of this process. These authors give :

$$\Gamma_{D^+\to e^+X} = \Gamma^{(0)}_{D^+\to e^+X}\, g(\varepsilon)\left[1 - \frac{2}{3\pi}\alpha_s(M_c^2)\, f(\varepsilon)\right] \qquad (1.4)$$

where $\varepsilon = \frac{M_s}{M_D}$ and f,g are functions given in reference[3].
They put M_s = .5 Gev and $\alpha_s(M_c^2)$ = .7 : getting :

$$\Gamma_{D^+\to e^+X} = 1.3\ 10^{11}\ sec^{-1} \qquad (1.5)$$

The constance of branching ratioes implies that ; as

$$\tau_M \equiv \frac{1}{\Gamma_{TOT}(M)} = \frac{BR(M\to e^+X)}{\Gamma(M\to e^+X)}$$

[redacted]

$$\Gamma_{M\to e^+X} = \frac{BR(M\to e^+X)}{\tau_M} \qquad (1.6)$$

where M stands for a charmed meson,

[redacted] lifetimes are proportional to branching ratioes :

$$\frac{\tau_{D^+}}{\tau_{D^0}} = \frac{BR(D^+\to e^+X)}{BR(D^0\to e^+X)} \sim 3 \qquad (1.7)$$

putting the quantities measured in ref [4]. This was the first indication that the neutral and the charged D could have different lifetimes.

Moreover, the measurement of the ratio $\frac{\tau(D^+)}{\tau(D^0)}$ allows us to check the equations (1.3) , (1.4) and (1.5), and to have indications on the strong coupling constant and the strange quark mass.

The conclusions will be given in chapter 5.

(E) Leptonic decays .

We want to show that the width for purely leptonic decays are much smaller than the semileptonic ones.

We remind that the neutral D cannot decay into a lepton pair at the lowest order in the Fermi coupling constant (this derives from the non existence of neutral weak currents violating strangeness and charm) , so we restrict ourselves to charged charmed mesons.

In general, the matrix element for the decay of a pseudoscalar charged meson into a charged lepton and a neutrino is :

$$\mathcal{M} = \frac{G}{\sqrt{2}} \langle M^+(p) | J^{\nu}_{hadr.} | 0 \rangle \langle 0 | J^{\nu}_{lept.} | \ell^+ \nu_\ell \rangle \tag{1.8}$$

Defining

$$\langle M^+(p) | J^{\nu}_{hadr.} | 0 \rangle = a_M p_\nu \tag{1.9}$$

one gets

$$\Gamma_{M^+ \to e^+ \nu} = \frac{1}{8\pi} G^2 a_M^2 m_\ell^2 M_M \left(1 - \frac{m_\ell^2}{M_M^2}\right)^2 \tag{1.10}$$

We see that the favoured decay is the one in the heaviest lepton.

The constant a_M , whose dimension is a mass, is usually expressed in pion masses:

$$a_M = f_M m_\pi \tag{1.11}$$

Assuming SU(4) symmetry we can put :

$$\left.\begin{aligned} f_{K^+} &\simeq f_\pi \sin\theta \\ f_{D^+} &\simeq f_\pi \sin\theta \\ f_F &\simeq f_\pi \end{aligned}\right\} \tag{1.12}$$

f_π has been measured in the pion decay and it is about .9,

At last we get the following predictions :

$$\left.\begin{aligned} \frac{\Gamma(D^+\to e\nu)}{\Gamma(D^+\to N\nu)} = \frac{\Gamma(F^+\to e\nu)}{\Gamma(F^+\to N\nu)} &\cong 2.5\ 10^{-5} \\ \Gamma(D^+\to N\nu) &= 1.6\ 10^{8}\ \mathrm{sec}^{-1} \\ \Gamma(F^+\to N\nu) &= 7.3\ 10^{9}\ \mathrm{sec}^{-1} \end{aligned}\right\} \qquad (1.13)$$

So the rate into $N\nu$ is really negligible. We must, however , take into account the new lepton τ (1782 Mev) and we obtain :

$$\left.\begin{aligned} \Gamma(D^+\to \tau^+\nu_\tau) &= 3.4\ 10^{8}\ \mathrm{sec}^{-1} \\ \Gamma(F^+\to \tau^+\nu_\tau) &= 4.8\ 10^{10}\ \mathrm{sec}^{-1} \end{aligned}\right\} \qquad (1.14)$$

This phenomenon could be relevant for the F meson :

$$\frac{\Gamma(F^+\to \tau^+\nu_\tau)}{\Gamma(F^+\to e^+X)} \cong .37 \qquad (1.15)$$

(F) Hadronic decays .

Since the leptonic decays are negligible and the semileptonic widths seem to be independent on the spectator quark, different values for charmed meson lifetimes can be explained only in terms of purely hadronic weak transitions.

Only matrix elements in the highest order in Cabibbo angle will be considered, and this hypothesis is correct at a level of 5% .

In this approximation, the diagrams that contribute to hadronic decays are :

- for charged D^+ the radiation one (number 3 in section 1.C) ,
- for neutral D the radiation and the exchange ones (5 and 6) ,
- for F the radiation and the annihilation ones (9 and 11) .

The radiation graph itself leads to a hadronic width :

$$\Gamma_h = N_c \cdot \Gamma_{e^+X} \tag{1.16}$$

where N_c is the number of colours .

In this picture we get

$$\Gamma_{D^+\to all} = \Gamma_{D^+\to e^+X} + \Gamma_{D^+\to \mu^+X} + \Gamma_h \tag{1.17}$$

Because of (1.16) we obtain :

$$\Gamma_{D^+\to all} = 5\ \Gamma_{D^+\to e^+X} \tag{1.18}$$

Very interesting predictions are :

$$BR(D^+\to e^+X) = BR(D^+\to \mu^+X) = 20\% \tag{1.19}$$

$$BR(D^+\to \text{hadrons}) = 60\% \tag{1.20}$$

$$\Gamma(D^+ \to e^+ x) = 1/5 \cdot \tau(D^+ \qquad (1.21)$$

So a measurement of D^+ lifetime, assuming that (1.21) is correct, will indicate which of the 2 equations (1.3 or 1.4) is more reliable.

On the contrary, the D^0 and F decays can take place through other 2 diagrams . The bare annihilation graph, that could be responsible of a fraction of the F decays , is depressed for helicity reasons and its width has a very similar form to equation (1.10). However it can be modified with gluon radiation or with the presence of gluons or quark-antiquark pairs (see FIG[2] and ref[5]) that would let the c and s quarks to be in a state with spin 1. According to Rosen's paper [6] , this effect should be less than 15%.

So the hadronic width for F can be written :

$$\Gamma_{F^+\to\ \text{hadrons}} = \left| A_{\text{RAD.}} + A_{\text{ANN.}} \right|^2 \qquad (1.22)$$

For the neutral D we get a similar result, because, even if the exchang diagram is different from the annihilation one, the same arguments can be applied :

$$\Gamma_{D^0\to\ \text{hadrons}} = \left| A_{\text{RAD.}} + A_{\text{EXCH.}} \right|^2 \qquad (1.23)$$

Of course,a separation of the two amplitudes could be possible only if one is much greater than the other.

A very interesting calculation can be performed assuming the Cabibbo angle equal to 0 and looking at the transformation properties of the weak Hamiltonian. We give a trace of it .

As $$J_{\text{hadronic}} \sim 4 \otimes \bar{4} = 15 \oplus 1 \quad ,$$

$$H \sim 15 \otimes 15 = 84 \oplus 45 \oplus 45 \oplus 20 \oplus 15 \oplus 15 \oplus 1 \qquad (1.24)$$

Only 20 and 84 contribute, and they are decomposed in SU(3) representations according to the following table :

$\Delta c \rightarrow$ / REPR. ↓	+2	+1	0	−1	−2
20		$\bar{6}$	8	6	
84	$\bar{6}$	$\bar{3} \oplus \overline{15}$	$27 \oplus 8 \oplus 1$	$3 \oplus 15$	6

(1.25)

We assume 2 amplitudes M(20) and M(84) and take into account only representations with $\Delta c = -1$. The only elements different from 0 are:

$$6_{22} = M(20)\, A^1_2\, A^3_0$$

$$15^{31}_2 = 15^{13}_2 = \frac{M(84)}{2}\, A^3_0\, A^1_2$$

Defining $\quad w_1 = D^0 , \quad w_2 = D^+ , \quad w_3 = F^+ \quad$ we get

$$(6 \otimes w)_{sym} = 8$$

$$(15 \otimes w)_{sym} = (8 \oplus 27 \oplus 10)_{sym} = 8 \oplus 27$$

we see that in the final state the 2 representations do interfere, and the final SU(3) states will be (see FIG[3])

$$\left.\begin{aligned} 8^3_2 &= \left[-M(20) + M(84)/2\right] A^3_0 A^1_2\, w_1 \\ 8^1_2 &= \left[M(20) + M(84)/2\right] A^3_0 A^1_2\, w_2 \\ 27^{31}_{22} = 27^{13}_{22} &= M(84)\, A^3_0 A^1_2\, w_2 \end{aligned}\right\} \qquad (1.26)$$

So we get the predictions :

$$\left.\begin{aligned} M_{D^0 \to \text{hadr}} &= -M(20) + \frac{M(84)}{2} \\ M_{D^+ \to \text{hadr}} &= -M(84) \\ M_{F^+ \to \text{hadr}} &= M(20) + \frac{M(84)}{2} \end{aligned}\right\} \qquad (1.27)$$

CHAPTER 2

"Experimental Features of a Charm-Lifetime Experiment "

(A) General Remarks

From the experimentalist's point of view, a charmed event is marked by the following features :

- The number of prongs in the final state, due only to the decays of the charmed particles, is high ,
- The production rate is low ,
- The decay-lengths of the charmed particles are about 1 mm. from the production point (this distance is only a mean reference value, as it is heavily dependent on the production mechanism) .

So,to perform a charm-lifetime measurement, experimentalists must build and match a vertex detector and a spectrometer for neutral and charged prongs, able to work at high multeplicities .

Anyway, the fundamental choice is that of the production mechanism, choice that sets very tight limits and conditions on the vertex detector as well as on the spectrometer .

The main mechanisms to produce bare charmed particles are :

(i) E+E- into hadrons ,

(ii) Gamma+Nucleus into hadrons (diffractive or not) ,

(iii) Neutrino+Nucleus into hadrons ,

(iv) Pion,Proton+Proton(or Nucleus) into hadrons .

We discuss now briefly these production mechanisms , then how to identify a charmed event (with its weak decay) and introduce the main experiments which deal with them .

(B) A Short Review of Production Mechanisms

The production at electron-positron storage-rings has yielded, so far , the most copious production of charmed mesons [7] , but only recently has given some results about their lifetimes.

This happens because in E+E- interactions, the charmed mesons are made with very low momenta in the laboratory frame system .

It is necessary to go up to 14.5+14.5 Gev to enhance their decay lenghts in a detectable way : in this case the vertex detector consists in the chambers placed around the interaction point (of course, they should have sufficient precision) .

An experiment of this kind will be described in chapt. (3.B) .

It is worth mentioning that for some experiments in the next generation (CDF at Fermilab proton-antiproton collider, ALEPH at LEP-CERN) it is planned to identify secondary vertices with multi-electrode-silicon-detectors [8] placed just around the interaction point, well inside the beam-pipe .

--- The photoproduction off complex nuclei must be divided into diffractive and non-diffractive part .

The former can be theoretically understood [9] with the direct coupling of the photon to a charmed vector meson (see FIG[4]) which exchanges a Pomeron with the nucleus, the charmed meson decays strongly into one pair of bare-charmed mesons (or baryons) .

Inside the diffractive photoproduction, we can define a coherent part, whose charateristic is the recoil of the nucleus as a whole, without evaporation of nuclear fragments (neutrons or protons or alpha).

A coherent interaction can take place only if the photon energy is greater than

$$E > 25*A^{1/3} \quad Gev \qquad (2.1)$$

where A is the atomic number of the nucleus used as target .

Diffractive photoproduction is also marked by the fact that the outgoing particles concentrate themselves in the diffractive cone of the incoming photon, that is inside an angle

$$THETA < M/E \qquad (2.2)$$

where M is the invariant mass produced and E the photon energy .

On the other hand, the non-diffractive photoproduction is also present, which is marked by the very likely breaking of the nucleus, that can spoil in an unrecoverable way the tracks near the interaction point .

Anyway, coherent as well as incoherent productions must fight against the copious E+E- background, but have the great advantage of a larger counting rate (some orders of magnitude bigger than the E+E- case) and of a great gamma-Lorentz factor for the charmed mesons. This phenomenon enhances up to some millimeters the decay-lengths (diffractive case at a photon energy of 100 Gev)

--- The charm production with high-energy neutrino beams is based upon the reversed mechanism of the charm decay , calculations can be done in the parton model and give, of course, very low value for cross-sections.

So the number of collected events is always little and there is the need to work with large targets, on the contrary there are also very few background events and this is essential when working with photographic emulsions or with any non-triggerable instrument .

--- The charm hadronic production, which has a cross section of 10/20 microbarns at 400 Gev [10] , can , as in the photoproduction case, be divided into a diffractive and non-diffractive part.

Since at present there is no satisfactory theory of the strong interactions, the hadronic charm production off nuclei (or nucleons) can only be treated or explained with the aid of phenomenological models such as the parton model (and its developements) .

We do not discuss any of these models, but we only say that the non diffractive hadronic production is characterized by the presence of many pions and nuclear fragments that are placed upon the charm decay products and that make almost impossible a clear reconstruction of the event .

Diffractive production has very similar features to the diffractive photoproduction , and , as experimental results [11] show , is a good method to get charmed events , as we shall discuss better in chapter 4 .

(C) Identification of a charmed event.

As we have seen in chapter 1 , charmed meson decays are marked by a lifetime of about 10**-13 seconds , and by the presence of strange particles (mainly kaons) in the final state .

The latter statement does not hold in the case of Cabibbo suppressed decays , which occur in the 5% of the cases .

So, there are two ways of identifying them :

- to observe a peak in invariant mass of systems like $K+n\pi$ and then look at decay lengths ,
- to look in the vertex for decays corresponding to lifetimes in the charm expected range and check if the spectrometer's answer is consistent with a charmed meson .

The former is certainly a non-biased measurement of lifetimes , but it is restricted to fully-reconstructed events , in which all prongs coming from a charm decay are identified and measured in momentum .

In this case we are bounded to lose all semileptonic decays (10-40%) in which a neutrino is emitted , we are also subjected to a large combinatorial background that can overwhelm the signal .

It is a method that is is suitable for hadronic decays , so the spectrometer should have the following features :

- a magnetic analyzer , able to work with high (up to 10) charged multiplicities with a good momentum resolution (1% or less),

- elettromagnetic detectors for electron/hadron discrimination and photon energy measurement , to reconstruct neutral pions ,
- Cerenkov or dE/dx or time-of-flight counters to discriminate among kaons , pions , protons and electrons .

Of course, only high statistic experiments can try to build a peak in the invariant mass of charmed mesons : so far only two purely electronic experiments , the CERN-NA1 and the SLAC-MARK2 ones ,have succeeded in recontructing D-meson mass as well as in measuring its lifetime .

The other experiments , which operate with hybrid techniques , must base themselves on decay-length measurements : this procedure could , in principle , bias the measurement itself , so corrections must be taken into account .

Hybrid techniques (photographic as well as emulsion ones) cannot operate at high counting rates and , apart from streamer chambers , are not triggerable devices : here the charm signature comes from the vertex part of the experiment which produces a picture of the event , where one can see series of tracks departing from the interaction point , followed by other tracks starting from a secondary vertex .

The spectrometer has the role to confirm the observation made in the vertex and to measure the momenta of the various particles in order to reconstruct the original momentum of the charmed particles .

It is interesting to remark that , even if one particle in the final state is missing , it can be identified with the aid of conservation rules , such as the leptonic number one (and the baryonic one) , and making the guess that it has been a Cabibbo-favoured decay : usually these events are reported in the literature , but with less credit .

(D) Experiments looking for charmed meson decays .

The experiments which have looked (or are looking) for charmed meson decays are summarized in the following table :

LABORATORY	ABBREV.	VERTEX DETECTOR	BEAM,ENERGY	OBSERVED DECAYS
FNAL	E247	Emulsion	Neutrino [illegible],	2
"	E382	Emulsion	Muons	1 (?)
"	E490/630	Streamer ch.	Protons,Neutrons	-
"	E531	Emulsion	Neutrinos [illegible].	35
"	E553	Emulsion	Neutrino	1 (?)
"	E564	Emulsion	Neutrinos [illegible].	1
SLAC	MARK-II	Drift chamb.	E+E- 14.5+14.5	7
"	BC72/73	Bubble chamb.	photons 20 Gev	27
CERN	WA17	Emulsion	Neutrinos, peak 25 G.	8
"	WA45/58	Emulsion	Photons 20/70 Gev	27
"	NA1	Silicon target	Photons 70/150 Gev	103
"	NA16	Bubble ch.	Pions,Protons 360 G.	30
"	NA18	Bubble ch.	Pions 340 Gev.	21

We shall discuss now in a more technical way the various experiments

(chapters 3 and 4) , dividing them according to their vertices , at last (chapter 5) we discuss their results and give the lifetimes of D and F mesons .

CHAPTER 3

Experiments with Purely Electronic Techiques

(A) Semiconductor techniques : The CERN-NA1 experiment .

NA1 CARD [12]

Beam............ tagged photon beam 70-150 Gev

Target.......... ,Active multilayer silicon target

Vertex detector. The above mentioned target

Physical reaction Photon+Silicium into Silicium nucl.+pair of charmed mesons (coherent)

For this reaction:

- acceptance.. 100% for charged particles and photons
- dP/P (charge) < 1% in the range $2 < P < 100$ Gev
- dE/E (photon) $.15/\sqrt{E}$ or $.4/\sqrt{E}$ (E in Gev) depending on the detector

E/hadron discrim with electromagnetic shower detectors

pion/K discrim. with 2 Cerenkov counters in the range $5<P<21$ Gev

Observed decays:

- neutral D... seen
- charged D .. 98 , including 10% backround

- F .... 5 , backround < 1 event

Integrated luminosity : 30 events/nanobarn

Data taking period : feb/apr 1980

The NaI experiment (FIG[5]) makes use of a tagged photon beam , whose energy lies in the range 70-150 Gev , produced by bremmstrhalung of an electron beam (150 gev in energy)

This experiment deals only with coherent photoproduction of charmed meson pairs off Silicon and studies only hadronic charm decay .

The coherence of the events is insured on-line (i.e. at trigger level) by a set of veto scintillator counters surrounding the target and therefore rejecting nuclear fragments produced in incoherent interactions, by the request that all the particles go inside the diffractive cone of the projectile (100 mrad. in the forward direction) and off-line by the coherence signal in the target .

In the coherent reaction , the silicon nucleus recoils as a whole with a mean kinetic energy of about 500 Kev (the spectrum of this energy is shown in FIG[6]) and it stops by ionization energy loss in a few microns.

The target[13] is made by 40 silicon detectors (see FIG[7]) , 300 microns thick, 100 microns apart . Each of them has one golden surfaces and the other one alluminized and it is reverse-biased with a voltage of some tens of volts . A ionizing particle raises electrons from the valence band to the conducting one : this charge , proportional to the energy release , is collected and recorded .

The noise is due in part to the fluctuation of the reverse current (FIG[8]), in part to the noise of the electronic chain (amplifiers and so on) : it corresponds to a random energy release of 25-30 Kev . On the other hand , the signal of a minimum ionizing particle is - on average , because of Landau fluctuations - 90 Kev (FIG[9]) .

In FIG[10-11] are shown the signals coming from one element of the NA1 target for an electron beam : the peaks are the pedestal, the 1-particle and the 3-particle signals respectively the signals for a photon beam are reported in fig[11] : the pedestal and the 2-particles peacks are well evident and the resolution is good .

In FIG[12] we present some typical photoproduced events :

-a) is an electron-positron pair creation ,

-b) is a non-coherent event

-c) is a coherent 2-pions production ,

-d) is a good charm event .

This last picture clearly shows the signal of the nucleus recoil, then a 2-particle signal ,followed by the decay of one of them into 3 charged prongs.

The vertex ---

Apart from the target , the vertex itself contains a set of veto counters and 2 multiwire proportional chambers about 60 cm. downstream of the target, with the aim to help the spectrometer to reconstruct complicated evnts or events in which a neutral kaon decays in flight (a K-short with a momentum of 5 Gev has a decay - length of 30 cm.) .

The spectrometer ---

The spectrometer , in order to get the wanted resolution and to separate the photons from neutral pion decays , has a modular structure.

Each module (repeated 4 times) consists of a bending magnet, of a set of drift chambers and of a shower detector for photons and electrons .

The drift chambers , described in ref [14] , have a spatial resolution of .1 mm. (FIG[13]) , that allows the wanted precision on charged particle momentum. ,

The shower detectors (ref [15]) are made of lead glass matricies apart the first module of the spectrometr , which consists of a lead scintillator sandwich : this dishomogeneity (mainly due to economical reason since the first photon detector is very large) does not spoil the overall resolution of the spectrometer .

The energy resolution for the photons fits well the formula

$dE/E = A/\sqrt{E} + 0.02$, where

A=.15 for lead-glass and A=.40 for lead-scintillator systems , the spatial resolution is about 2 mm.

Each shower detector has been longitudinally divided into two parts , named front and back (FIG[14]). The front part consists of 4 radiation lengths, the back one 16 : this enables to distinguish between electrons (whose showers start in the front part) and hadrons (that give signal in the front part only if they interact strongly, which happens only in 20% of the cases).

Scintillator counters are placed in front of each photon detector to distinguish between neutral and charged prongs .

Moreover, there are other two shower detectors : the former in front of the first magnet to identify large angle particles coming , for istance, from the decay D^* into $D\gamma$, the latter at the end of the spectrometer on the beam-line, to detect photons coming from a double-emission process in the target .

The first two magnets are filled with two multicell gas Cerenkov counters , which discriminate between pions and kaons in the range 5-21 Gev (ref [16]).

Trigger conditions ---

The trigger of the experiment must have the following features :

-a) a power rejection for e+e- pairs(defined as the number of events produced dividedby the number of unwanted events accepted in the trigger) better than 5*10**4 ,

- a power rejection on incoherent hadronic events better than 20
- an acceptance for coherent hadronic events better than 70 % .

The numbers given before can be understood in the following way : the beam intensity is 10**6 photons (with energy > 2Gev) per burst and the maximum number of events that can be recorded on tape is 50 . So the e+e- pairs, with enough energy to pass the first magnet, are 1.4*10**4 per burst, because the target is .15 radiation length .

The total inclusive incoherent cross-section photon-nucleon into hadrons is about 100 microbarns, so the rate of incoherent events is 180 per burst.

We cannot allow ourselves to crowd the data with too much unwanted events : from here the necessity of such tight trigger.

Moreover the rate of diffractive charm events is expected to be :

R(ev./burst)= I*L*D*SIGMA*n/A

where I is the beam intensity
L is the target length
D is the target density
SIGMA is the cross-section
N is Avogadro's number
A is the atomic number

Substituing the proper values , one obtains :

R = .16 ev/brst = 48 ev/hour

This number is the rate for all channels , also for those that escape reconstruction, because of long-lived neutral kaons or neutrinos in the final state : taking these effects into account, the rate for detectable channels - assuming the apparatus efficiency to be 1 - iss 23 ev/hour.

I would stress that mostly of the events recorded are coherent non-charmed ones (mainly R0 and its recurrences) : in fact the diffractive hadronic cross section on nucleon is about 10 microbarns, that implies a rate of 10 events/burst. Of course, these events have a different trigger efficiency respect to the charmed , due to their lower multeplicity.

Finally an event to trigger the appararus had to fulfill the following conditions :

- a neutral particle incoming,
  corresponding to a photon with an energy greater than 20 Gev :
  this yielded a rate of 5*10**5 particles/burst ,
- at least one charged prong outgoing, and no signal in the veto counters : this condition reduced the rate to about 10^5 events/burst mainly electromagnetic pairs ,
- at least one hadron in the spectrometer, hadron being defined as a particle that , hitting a photon detector, releases a very little energy in the front part : the rate was further reduced to 2000 ev/burst ,
- at least or another hadron or a photon in the spectrometer, the photon being defined as a neutral particle hitting a shower detector and releasing a lot of energy in the front part . This very tight requirement brought the rate to our wanted some events burst.

The trigger, in this configuration, is biased towards high muleplicity events: we can compute , in a rough but quick way, its efficiency for the reactions :

$$\gamma\, Si \rightarrow \pi^+\pi^-\, Si \qquad (i)$$

$$\gamma\, Si \rightarrow \pi^+\pi^-\pi^0\, Si \qquad (ii)$$

$$\gamma\, Si \rightarrow 2(\pi^+\pi^-)\, Si \qquad (iii)$$

$$\gamma\, Si \rightarrow n(\pi^+\pi^-)\, Si \qquad (iv)$$

If the online identification efficiency is h for hadrons (h = .7) and g for photons (g=.98) , we have as trigger efficiency :

(i) $h^2 = 50\ \%$

(ii) $h^2 + 2*(1-h)*h*g = 93\ \%$

(iii) $1-((1-h)^4 +4*h*(1-g)^3) = 95\ \%$

(iv) $1 - ((1-h)^{2n} + 2*n*h*(1-g)^{2n-1})$

Only the R0 photoproduction is depressed, but it still remains the most copious sample in NA1 data .

Analysis ---

During the data-taking period , 1.800.000 events have been collected, this sample has been reduced to 30.000 units requiring :

- (i) no electrons in the event ,
- (ii) an incident photon energy of more than 70 Gev ,
- (iii) at least 6 charged prongs .

Condition (i) protects against semileptonic decays of charmed mesons and against random coincidences with E+E- pairs produced by photons emitted simultaneously to the one that induces the hadronic reaction .

Condition (ii) is necessary for a diffractive production of pairs of charmed mesons .

Condition (iii) is a request to search for the decays of charged D into three charged particles, i.e. to be able to observe a multeplicity step in the target.

The successive step was to build all combinations that could give a pair of charmed mesons, requiring only Cabibbo-favoured decays : that is to search for a D in the channel K+pions and for an F in the channels $K\bar{K}$+pions, pions , ETA+pions .

The kaons were either identified in the Cerenkov counters or ambigous.

We put some tigh cuts around the mass of D and D* and plotted the invariant mass of the other D-candidate : a clear signal is visible in FIG[15] in correspondence of the masses of D and D* .

For the F meson the same procedure was followed, getting signals in the channels $\eta\pi^+\pi^-\pi^+\pi^0$ and $K^-K^+\pi^+\pi^0$ (FIG[16-17]), no clear evidence ,on the contrary was obtained in the channel $\pi^+\pi^-\pi^+\pi^-\pi^+$(FIG[18]).

At last, for all the events that had at at least one combination under the D and F peaks , the following requirements were requested:

(i) no ionizing particle signal in the first two layers of the target,

(ii) a level compatible with 2 or more minimum ionizieng particle in at least 4 layers following the interaction point ,

(iii) a successive increase of multeplicity of 2 or 4 or 6 .

Condition (i) ensures that the interaction did take place inside the target. Condition (ii) is necessary to confirm the presence of 2 (or more) stable charged particles, because it protects against Landau fluctuations, but has the unpleasant feature to set a lower limit on the the measurable lenght of about 1.6 mm.. We stress that a particle with a lifetime of 10*-13 sec. (as neutral D is supposed to have) and produced with a gamma-Lorentz factor of 20 is detected in the 35% of the cases, this percentage is 75% for charged D . Condition (iii) is the natural signature for a decay.

We have observed in the D sample 98 decays in 86 events (12 times the target shows a double step) , while 5 decays have been recognized in the F sample) in FIG[19] we show the deay time distribution (ref. [17]).

Unfortunately, we often cannot attribuite the two reconstructed energies to the candidate whose deacay has been observed. This is obvious every time that there is a combination with two charmed mesons decaying with the same multeplicily, i. e.

$$D^+ D^- \longrightarrow K^- \pi^+ \pi^+ \pi^0$$
$$\hookrightarrow K^- \pi^+ \pi^+$$

However the number of combinations per event is high, so it usually happens that exchanging some pions - it does not matter if charged or neutral ones - the invariant masses are still in the D zone : in this case we can do nothing better that attribute to the D candidate the " mean energy " of the two reconstructed charmed mesons .

This also implies that the charmed mesons and the neutral must be put , all together, in the same plot : since their lifetimes can be different , we should see a double-exponential behaviour in the decay-time histogram.

As our sample is richer in D+ than in D^0 because of condition (ii), we note only (see FIG[19]) a slight enhancement for little time of flight, in agreement with a 20 % contamination of neutral D having a lifetime in the range from 1 to 4*10**-13 sec.

Taking into account corrections for this effect and for the finite lenght of the target (see also chapter 5) we give for the charged D lifetime the value :

$$\tau(D^{\pm}) = 9.5^{+3.1}_{-1.9}\ 10^{-13} \text{ sec.}$$

The 5 F events has given the result:

$$\tau(F^{\pm}) = 5.0^{+5.0}_{-2.5}\ 10^{-13} \text{ sec.}$$

Further improvements ---

In August 1982 the photoproduction program of NA1 experiment has restarted with some modification in the apparatus , devoted in particular to get a better resolution on D+ lifetime and to perform the measurement of the neutral one .

This goal should be reached substituting the target used in 1980 with a new one , made of Germanium. In fact the D^0 lifetime measurement was prevented by the resolution of the target, while the large error on the D+ one was due to the finite lenght of the target.

The new one consists in a block of Germanium .5 cm thick, with a section of 2.5 x .5 cm. (FIG[20]) Its lower surfaces is golden ,while on the upper one are placed , with the aid of printed-circuit techniques , 48 golden strips, 50 microns wide , 50 microns spaced, and directed orthogonal to the beam.

Between the two metal surfaces it is applied a voltage to deplete completely the semiconductor material : a ionizing particle induces electron-vacuum pairs which drift and induce on the strips a signal proportional to the energy releases. The pattern recognition is similar to the Silicon case.

In addition to the Germanium block and behind it, there are also 15 thin (200 microns) silicon detectors that enhance the measurable decay-path to some centimeters.

The better granularity and the greater length of the whole system should make possible a better separation of the Do and D+ exponentials, and, one hopes, could give a measurement or a limit on the neutral D mixing, measurement which is feasible only with large statistic .

At present (october 1982) the analysis on the new data is in progress.

(B) Decay-length Measurement techniques : The SLAC-MARK-II Experiment

SLAC - MARK-II CARD

Beam...................E+E- 14.5 + 14.5 Gev

Target.................none

Vertex detector........precision drift chambers around the beam pipe

Physical reaction...... $e^+e^- \to D^{*\pm} X$
$\hookrightarrow D^0 \pi^\pm$
$\hookrightarrow K^\mp \pi^\pm$

For this reaction :

- acceptance for charged...100%
- e/hadron discrimination..electromagnetic calorimeter
- pion/K discrimination....time of flight techniques

Observed decays :

- charged D...............none
- neutral D 7
- F ....none

Integrated luminosity.......17 ev/pbarn

Data taking period..........Dec 1981 - June 1982

In this section I shall describe a very recent measurement performed by the SLAC - MARK-II experience, that ,so far, has been mainly devoted to the study of the E+E- annihilation into hadrons.

The charm production in positron-electron colliders has hold the most copious (see, for istance ref [7]) results on charm, thanks to the the large number of charmed resonances (charmonium states , see [18]) in the energy range 3.0 - 4.5 Gev

At these energies the decay lengths of charmed particles are well inside the interaction region, so Mark-II people have gone to $\sqrt{s}$ = 29 Gev to study this phenomenon.

--- Apparatus ---

The apparatus consists in the drift chamber and in the electromagnetic calorimeter that form tha Mark-II central detector , whose constructing details are reported in ref [19] .

In addition to it, some high-precision (100 micron in position) drift chambers have been set just outside the beam pipe, to help the recostruction of secondary vertices.

The beam-pipe itself has been, around the interaction point, substituted by a new one made of Berillium, in order to decrease its thickness to 0.006 radiation lengths. This reduces the track-dispersions due to muitiple scattering. The extrapolated error is , for a single track, given by the following formula :

$$\sigma = \sqrt{(90)^2 + (100/p)^2}$$

where sigma is in microns and P in Gev/c.

--- Analysis [20] ---

We must stress that very few event are expected to be collected, because the reaction studied is performed at an energy far beyond the resonances region and because the branching ratio fo the decay D^{o} into K+pion is only 1.8 % .

The succesive step of the analysis were :

(i) build up all neutral combination kaon+pion and select all of them with invariant mass in the range 1.76-1.96 Gev ,

(ii) impose the Do mass to all of these combinations ,

(iii) add a charged pion with opposite charge to the kaon (Cabibbo rule) and plot the difference $m(K\pi\pi)-m(K\pi)$ for Z(D*)>.6 (FIG[21]) and for Z(D*)>.4 (FIG[22]) : Z is defined as the ratio between the particle energy and the center-of-mass energy divided by 2. Z gets a physical meaning in the parton model , that schematizes D production (outo of the resonance region) with a virtual photon coupling to a pair of charmed-anticharmed quarks , and each of them dresses itself with other quarks and produces stable hadrons . Z is just the fraction of energy going from the charmed quark into the charmed hadron, and of course it lies in the range 0-1 .

The plot of FIG[20] is very clear, showing 7 events where expected to be for a decay D*-> D+pion , on the contrary the plot of FIG[21] is not clear at all. So MARK-II people decided to cut at Z = .6 and to look for decay-length in the above-mentioned 7 events .

--- Decay length measurement ---

For the selectioned events, the tracks of the Kaon and pion coming from the D decay were projected backwards and their intersection was fitted. The error on the decay-point is given with the aid of the above formula and turns out to be about 300-500 microns.

One must add to this error the uncertainty on the interaction point, that is to say the spot of the E+E- collisions : 500 microns along the beam direction and 50 microns in the tranverse one . The total error is, for Z=.7, about 700 microns, to be compared with the average value for the decay-length (500 microns).

In terms of lifetimes, this experiment yields with a maximum likelihood fit , the result :

$$\tau_{D^0} = \left(3.7 {}^{+2.5}_{-1.5} \pm 1.0\right) 10^{-13} \text{ secs.}$$

CHAPTER 4

" Experiments with hybrid techniques "

A) Bubble Chamber Experiments

The Cern-NA16 Experiment [21]

CARD

Beam.....................pions,protons 360 Gev

Target..................LEBC (LExan Bubble Chamber)

Studied Reaction........ π,p + H_2 into charm (inclusive)

For the studied reaction :

- dp/p (charged)...... .7% for P < 30 Gev
- dE/E (photon)....... $0.15/\sqrt{E} + 0.02$, E in Gev

Particle identification. dE/dx method (ISIS1)

Integrated luminosity... 7.8 ev/microbarn (pion beam) +

7.3 ev/microbarn (proton beam)

Observed decays :

- neutral D 14
- charged D 14
- F 3 .

The apparatus consists in the European Hybrid Spectrometer (EHS) , coupled to the Lexan bubble chamber [22] , that looks like a little cylinder 20 cm in diameter and 4 cm deep, filled with hydrogenum at 29.1 K.

It is tuned to give 80 bubbles/cm and each bubble has a mean diameter of 40 microns : this is sufficient to measure lifetimes greater than $3\cdot10^{-13}$ seconds with standard techniques .

In an improved version of the experiment this sensibility will be brought to about $10\cdot10^{-13}$ sec by means of holographyc technique [23].

In order to reject the large-bubble background, upstream the target there is a kicker magnet that deflects the beam out of the chamber, until the optimal sensitivity is reached .

The spectrometer , a double lever one , is composed by two magnets, drift and multi-wire proportional chambers, lead-glass shower detectors, trigger scintillators and a large dE/dx counter (ISIS1) for particle identification.

During the data -taking period, 350000 frames (pion beam) and 500000 (proton beam) were recorded. In these data, the background is mainly due effects :

(i) strange particle decays,

(ii) photon conversion into e+e- pairs,

(iii) secondary interactions in which the photon recoil is not visible. This last source of background is, however, heavily depressed because the target material is hydrogenum: it turns out to simulate less than 1 charm event, according to Monte-Carlo calculations and the available data.

So, NA16 people analysis efforts were devoted to reduce the strange decays and photon conversion backgrounds. They started considering the following topologies :

- 1,3 or more prongs for charged decays,
- 2,4 or more for neutral decays,
- events with tracks not pointing to primary vertices,
- increase of ionization.

Among the events with one of the previous features, they accepted only those with (see FIG[23])

$$L \cdot \sin\theta < .06 \text{ cm}$$

corresponding to a cut on lifetimes of $2\,10^{-12}$ sec. Then, kinematic analysis was required to reconstruct kaons, lambdas and photons, according to the following criteria :

(i) for 2-prong neutral decays :

- invariant mass for E+E- > 30 Mev,
- " " " $\pi+\pi$ > 520 Mev,
- " " " πp > 1130 Mev,

(ii) for charged 1-prong decays :

- transverse momentum of secondary prong > 250 Mev ,

(iii)for charged 3-prong decays:

- invariant mass of any E+E- > 30 Mev,

- the χ^2-probability for $K \to 3\pi$ < .01 .

The above conditions on invariant masses are the usual ways to identify strange particles, while condition (ii) is the only available criterium to identify a decay without change in charge multeplicity.

The computed background events are, after these cuts, less than 2 , while the number of charmed candidates is 70 (including lambdas).

Anyway, they removed all 1-prong decays and also all decays with a neutral unseen prong or with ambiguities (D/F , for instance), reducing the sample to 14 neutral D, 14 charged and 3 F. The maximum-likelihood fit yielded the following values

$$\tau(D^0) = 3.9^{+1.4}_{-.9} \quad 10^{-13} \text{ sec.}$$

$$\tau(D^+) = 9.2^{+4.4}_{-2.5} \quad 10^{-13} \text{ sec.}$$

$$\tau(F^+) = 1.9^{+1.7}_{-.8} \quad 10^{-13} \text{ sec.}$$

and

$$\frac{\tau(D^+)}{\tau(D^0)} = 2.4^{+1.5}_{-.8}$$

NA18 CARD [25]

Beam.......................pion 340 Gev

Target....................BIBC (Bern Infinitesimal Bubble Chamber)

Studied reaction.........pion+nucleon into charm (inclusive)

For this reaction :

- charged acceptance....99%
- dP/P (charged)........ < 1%
- no neutral prong identification

Observed decays :

- neutral D.......19
- charged D 7
- F .... 5 .

The CERN-NA18 experiment couples a high resolution bubble chamber to a streamer chamber used as spectrometer . It has not any detector for electromagnetic particles and therefore it cannot reconstruct neutral pions. It identifies charmed mesons in charged channels only , and does not try to distinguish kaons from pions.

The vertex bubble chamber has a very good spatial resolution (the bubble diameter is 30 microns and their density is about 300 bub/cm)

In the analysis, they divided the charm candidates according to the number of charged decay prongs : for instance, a $D^0 \to K^- \pi^+$ is a (0-2) type decay, moreover the set (see FIG[24]) the following cuts on decays :

$d < 20$ mm.,

$\phi < 7$ deggrees.

$1^\circ < \theta < 10^\circ$ for (1-1),

$1^\circ < \theta < 15^\circ$ for (0-2),

$\theta < 20^\circ$ for (1-3),

$\theta < 35^\circ$ for other kinds of decay .

Then they asked for no missing neutral prongs and that all the tracks are pointing inside the streamer chamber. The surviving events were analized in momentum and invariant masses were built, making the kinematical hypotesis on pions and kaons, and taking into account only Cabibbo-favoured decays . As in NA16 experiment, events with reconstructed neutral kaons or lambdas were skipped. At last, after corrections for minimum-detectable lengths, they gave the following values :

$$\tau(D^+) = \left(6.3 {}^{+4.9}_{-2.3} \pm 1.5\right) 10^{-13} \text{ secs.}$$

$$\tau(D^0) = \left(4.1 {}^{+2.6}_{-1.3} \pm .5\right) 10^{-13} \text{ secs.}$$

$$\tau(F^+) = \left(4.4 {}^{+5.0}_{-1.7} \pm 1.5\right) 10^{-13} \text{ secs.}$$

$$\tau(D^+)/\tau(D^0) = 1.5 \pm 1.0$$

The extimted number of baground events is 5, to be compared with 21 identified events .

SLAC-BC72/73 Experiment [26]

Beam .... photons 20 Gev

Target .... high resolution bubble chamber (HRO)

Studied reaction .... $\gamma p \rightarrow D\bar{D}p$, $D\bar{D}^{*}p$, $D^{*}\bar{D}p$, $D^{*}\bar{D}^{*}p$

For this reaction :

- acceptance for charged 100%
- acceptance for neutral 100%
- dP/P (charged)........ 1% at 7 Gev
- dE/E (photon) .... $(.84+4.8\sqrt{E})\%$

Particle identification.. Cerenkov counter + lead glass shower detector

Observed decays :

- charged 14
- neutral D 13
- ambiguous 4

This experiment has been performed at the SLAC hybrid facility The used beam is is an almost monocromatic photon beam, achieved the backscattering of laser light (4.66 ev) on 30 Gev electrons . (see FIG[25] for the beam spectrum) . Its intensity is 25 photon burst, which is low, but we have to take present that it is also a very clean beam, without any low-energy photon in coincidence, and so there is pratically no e+e- background.

The vertex consists in a H_2-filled bubble chamber, which can work in conventional mode (8/10 bubbles/cm, 300 microns diameter) as well as in a igh-resolution mode (70 b/cm, 55 microns diameter on a depth of field of ± 6mm.) . The latter working-mode is yielded triggering the chamber 200 microseconds after the beam passages .

The spectrometer is quite traditional, and it is composed by 4 sets of multi-wire chambers, 2 Cerencov counters and an e.m. shower detector. All detectors were darkened in the e+e- kinematic region.

The trigger required or one charged perticle in 3 stacks of the chambers or an energy release in the lead-glass wall : its efficiency is extimated to be 88% on hadronic events and 91% on charmed events.

The taken pictures were analysed according to the following requests:

- search for at least 2-charged prong decays ,
- search for secondary vertices within 1 cm. the primary one,
- search only in the full efficiency region of the bubble chamber,
- at least one of the secondary tracks must miss the the primary vertex of 110 microns,
- another track must miss the vertex of 40 microns,
- decay-length greater than .5 mm.

After these cuts, 14 charged decays (D+F+Λ) and 13 neutral (D^0) survive , there are 4 neutral/charged ambiguos, too. The expected background is less than 1 event. Most of these decays have a neutral prong which is unseen, anyway , assuming that the charged sample is a pure D one, one gets :

$$\tau\left(D^{\pm}\right)=\left(7.3\ {}^{+3.0}_{-2.5}\right)10^{-13}\ \text{secs.}$$

$$\tau\left(D^{0}\right)=\left(7.7\ {}^{+3.0}_{-2.5}\right)10^{-13}\ \text{secs.}$$

$$\frac{\tau(D^{+})}{\tau(D^{0})}=.9\ {}^{+.7}_{-.4}$$

(B) Experiments with photographic emulsion techniques.

WA58 CARD [27]

Beam .... photons 20/70 Gev

Target .... photographic emulsion

Studied reaction .... photon+nucleon into charm (inclusive)

Particle identification.. Cerenkov counter + electromagnetic shower detector

Observed decays .

- neutral D 19
- charged D 8
- F 3

The CERN-WA58 experiments (and its first version , WA45) has measured the charmed meson lifetimes with emulsion techniques in a tagged photon beam, whose energy lies in the range 20/70 Gev..

The vertex, that consists in 20 x 5 x .06 cm^3 photographic emulsions set at 5 degrees respect to the beam, is coupled to the CERN OMEGA [28] facility, which is a magnetic spectrometer equipped with a Cerenkov counter and an electromagnetic shower detector . Because of the tilt angle, the effective path of the beam inside the films is 6 mm. In the WA45 version, this experiment had spark chambers instead of drift ones in the spectrometer and more little films (15 x 3.5 x 0.06 cm^3) at an angle of 11 degrees.

It can only deal with incoherent and non-diffractive photoproduction : the beam energy is too little and the heavy nuclei in the target must break themselves to produce a pair of charmed particles.

The scan efficiency is almost constant for distances greater than 20 microns and drops to 0 under this distance. The analysis has been performed looking for decays with 2 or more charged particles in the secondary vertices. Only events matched with the spectrometer have been taken into account, although many of them (about 30 %) have at least a neutral particle which escaped detection.

In 32 interactions 58 decays have been observed, but only 38 were selected, yielding':

$$\tau(D^{\pm}) = \left(3.8 \begin{smallmatrix} +2.6 \\ -1.3 \end{smallmatrix}\right) 10^{-13} \text{ ses.}$$

$$\tau(D^{0}) = \left(1.4 \begin{smallmatrix} +.5 \\ -.3 \end{smallmatrix}\right) 10^{-13} \text{ ses.}$$

and

$$\frac{\tau(D^{+})}{\tau(D^{0})} = 2.7 \begin{smallmatrix} +2.1 \\ -1.1 \end{smallmatrix}$$

WA17 experiment [29]

CARD

Beam .... neutrino , broad band peak at 25 Gev

Target .... emulsion

Studied reaction .... neutrino+nucleon into charm (inclusive)

Observed decays :

- charged D ... 4
- neutral D ... 3

WA17 experience uses as spectrometer the Big European Bubble Chamber (BEBC) with photographic emulsions used as target (2 sets 10.5 l. and 21 l. respectively) . The experimental setup is completed by multiwire chambers between the emulsion and the bubble chamber and by an iron external muon identifier (EMI) to separate events induced by weak charged currents.

About 200,000 pictures were taken when the target was irradiated by the broad-band neutrino beam. The events were first searched in the bubble chamber and then in the emulsion in a box of .7x7x7 mm^3 around the backward projection.

They found 8 charmed candidates, divided as follows :

(i) 1 fully reconstructed ,

(ii) 2 reconstructed charged D,

(iii) 2 charged decays compatible with Λ or D^+ , because one neutral prong is missing,

(iv) 3 neutral decays (V topology) compatible with neutral D if a neutral is missing.

Making the assumption that these decays (apart (i)) come from D mesons, one gets :

$$\tau(D^{\pm}) = \left(2.5 \begin{smallmatrix} +2.2 \\ -1.1 \end{smallmatrix}\right) 10^{-13} \text{ secs.}$$

$$\tau(D^{\circ}) = \left(.53 \begin{smallmatrix} +.57 \\ -.25 \end{smallmatrix}\right) 10^{-13} \text{ secs.}$$

E531 Experiment [30]

CARD

Beam .... neutrino (broad band)

Target .... emulsion

Studied reaction .... neutrino + nucleon into charm (inclusive)

dP/P (charged) .... .013 + .005P (spectrometer) + .34P (fringe field)
+.29P (multiple scattering)

dE/E (neutral hadron) .... $1.1/\sqrt{E}$

dE/E (photon) .... $.14/\sqrt{E}$

Particle identification... Muon identifier, time of fligth counters,ionizati
in the emulsion.

Observed decays:

- neutral D .... 19 + 20 (these last preliminarly)
- charged D .... 5 + 6 (these last ambiguous)
- F 3

The FNAL E531 eperiments has reached the most copious statistics among neutrino-induced charmed experiences. The apparatus, has a very powerful particle identification and also a hadronic calorimeter to identify neutral hadrons (as long-lived kaons).

The methodology of the analysis is the same as other emulsion experiments but the much more information given by the spectrometer and a higher statistic allow a better reconstruction of the events.

Each event reconstructed in the forward spectrometer has been searched in the emulsion in a box of 4 x 4 x 20 mm around the predicted vertex .

Every charged track departing from it was followed for 6 mm to look for a decay, while neutral decays were searched in a cylinder of radius .3 mm and 1 mm deep.

Also semileptonic decays were looked for, and kinematic fits were made to reject the usual backgrounds.

The final charged sample contained 3 unambiguous F , 5 very probabily D , 6 ambiguous D, yielding :

$$\tau(F^{\pm}) = \left(2.0^{+1.8}_{-.8}\right) 10^{-13} \text{ secs.}$$

$$\tau(D^{\pm}) = \left(11.4^{+6.6}_{-4.4}\right) 10^{-13} \text{ secs.}$$

A bit more complicated (and interesting) is the neutral D sample. It can be divided into semileptonic, hadronic and from $D^* \to D^0 \pi^+$ parts. (The last is built as MARK-II experiments) These parts have been marked by different values of lifetimes, according to the following table :

KIND OF EVENT	RUN 1		RUN 2		ALL RUNS	
	EV.	LIFETIME($\cdot 10^{-13}$ s)	EV	LIFETIME $\cdot 10^{-13}$ s.	EV	LIFETIME $\cdot 10^{-13}$ s.
$D^{*+} \to D^0 \pi^+$	6	$1.9^{+1.2}_{-.6}$	6	~ 5.8	12	~ 3.9
semileptonic	3	$6.3^{+6.2}_{-2.2}$	3	~ 3.6	6	~ 5.0
hadronic	16	$2.3^{+.8}_{-.5}$	17	~ 4.1	33	~ 3.2
ALL	19	$3.2^{+1.0}_{-.7}$	20	~ 4.0	39	~ 3.6

The fitted lifetime is $\left(3.17^{+1.0}_{-.7}\right) 10^{-13}$ s., i.e. the one corresponding by period 1, as the analysis for period 2 is still in progress.

The final neutral D sample should be 80, and this could allow to understand whether the different values of lifetimes are due to fluctuations or to physics (for instance neutral D mixing as in the kaon case).

(C) Other experiments

Apart the above experiments, others have been performed to detect charm decays. Some of them have been only tests, others have been limited by statistics or are very early experiences. We give a very short summary of their features and results.

E247 (ref [31]) - Fermilab.

Emulsion techniques, 1 charged track observed (182 microns, $6\cdot10^{-13}$ sec)

E382 (ref [32]) - Fermilab

Emulsion technique, muon high-energy beam, one V-event observed

E553 (ref[33]) - Fermilab.

Emulsion , muon beam, 2 events observed (200 micr, 32 micr)

E564 (ref[34]) - Fermilab

Emulsion, neutrino beam, one F-consistent event observed (504 microns)

E490/E630 (ref[35]) - Fermilab

This section deals with an experience (the FNAL E490/E630 one) which, although it has not yet observed charmed decays, proposes itself as a very interesting improvement for detecting short-lived particles.

The working principle of a streamer chamber (to apply a very short and intense voltage after some hundreds nanoseconds the passage of a ioniziong particle) allows to record just the events we want and to build very selective triggers for experiments.

A typical event from E630 experience is shown in FIG[26] (from J.Sandweiss , ref[36]) : the stramer diameter is 50 microns and the track width is 80 microns , mainly due to diffusion of primary electrons.

CHAPTER 5

Conclusions

(A) Experimental data on semileptonic branching ratioes

In this section I shall compare , whenever possible , the available data with the equations derived in chapter 1 .

We do not deal with predictions on hadronic branching ratioes, which, although very interesting, are, from a theoretical point of view, too much dependent on the authors' treatements and, from an experimental one, suffer because of statistics and a for the lach of proper calculation of efficiences in many-body channels.

The semileptonic branching ratioes are a little more established. DELCO and Mark-II experiments measured the excess of positron , and got the following values [4] :

$$BR(D^0 \to e^+ X) = (5.5 \pm 3.7)\% \qquad (5.1)$$

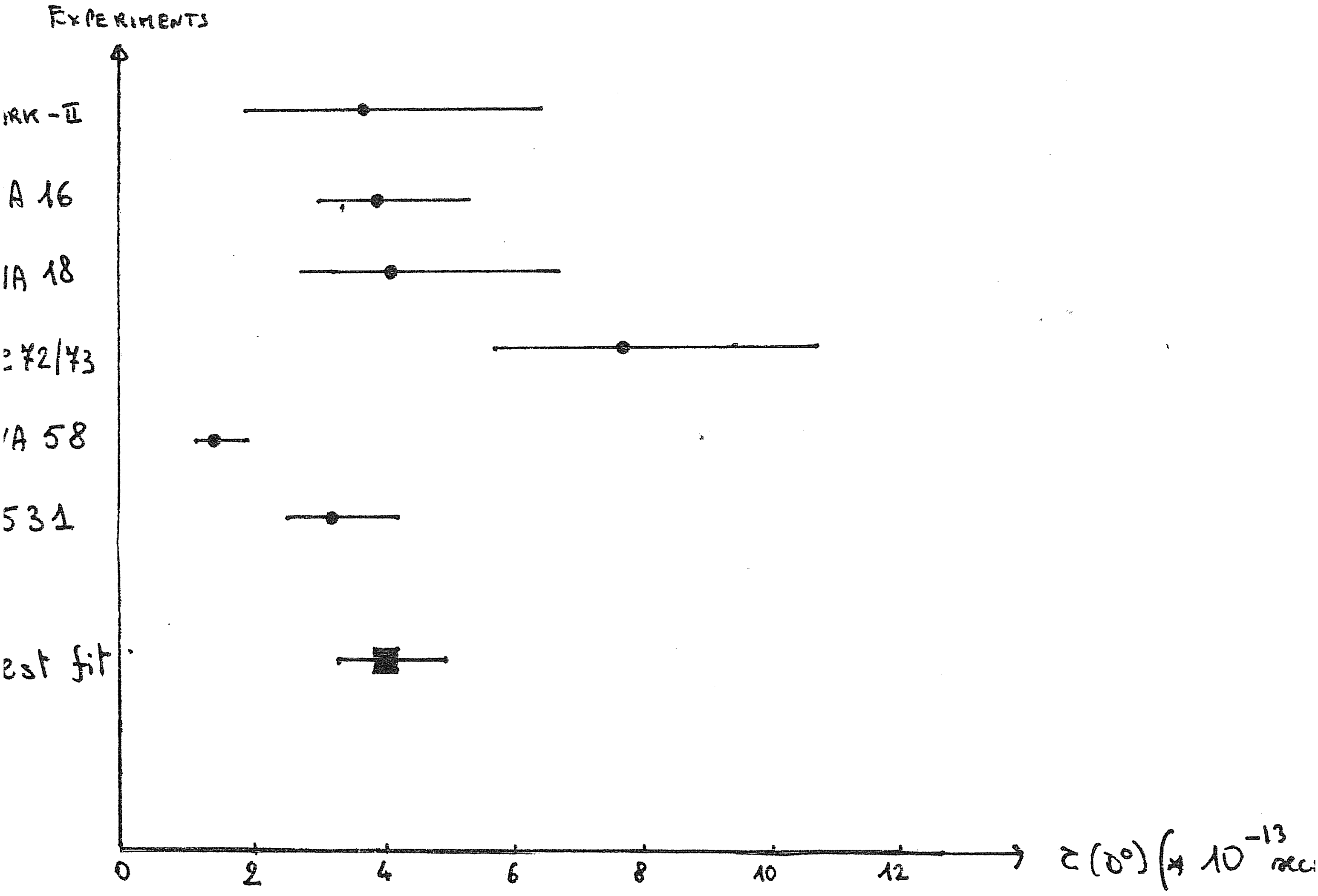
$$BR(D^+ \to e^+ X) = (19^{+3}_{-2})\% \qquad (5.2)$$

If we assume that leptonic decays are negligible, the above equations express the half of semileptonic branching ratioes.

(B) Experimental conclusions on lifetimes .

We summarize the experimental results on D and F lifetimes, taking into account only experiments with relevant statistics.

The neutral D measured lifetimes are reported in the following table :



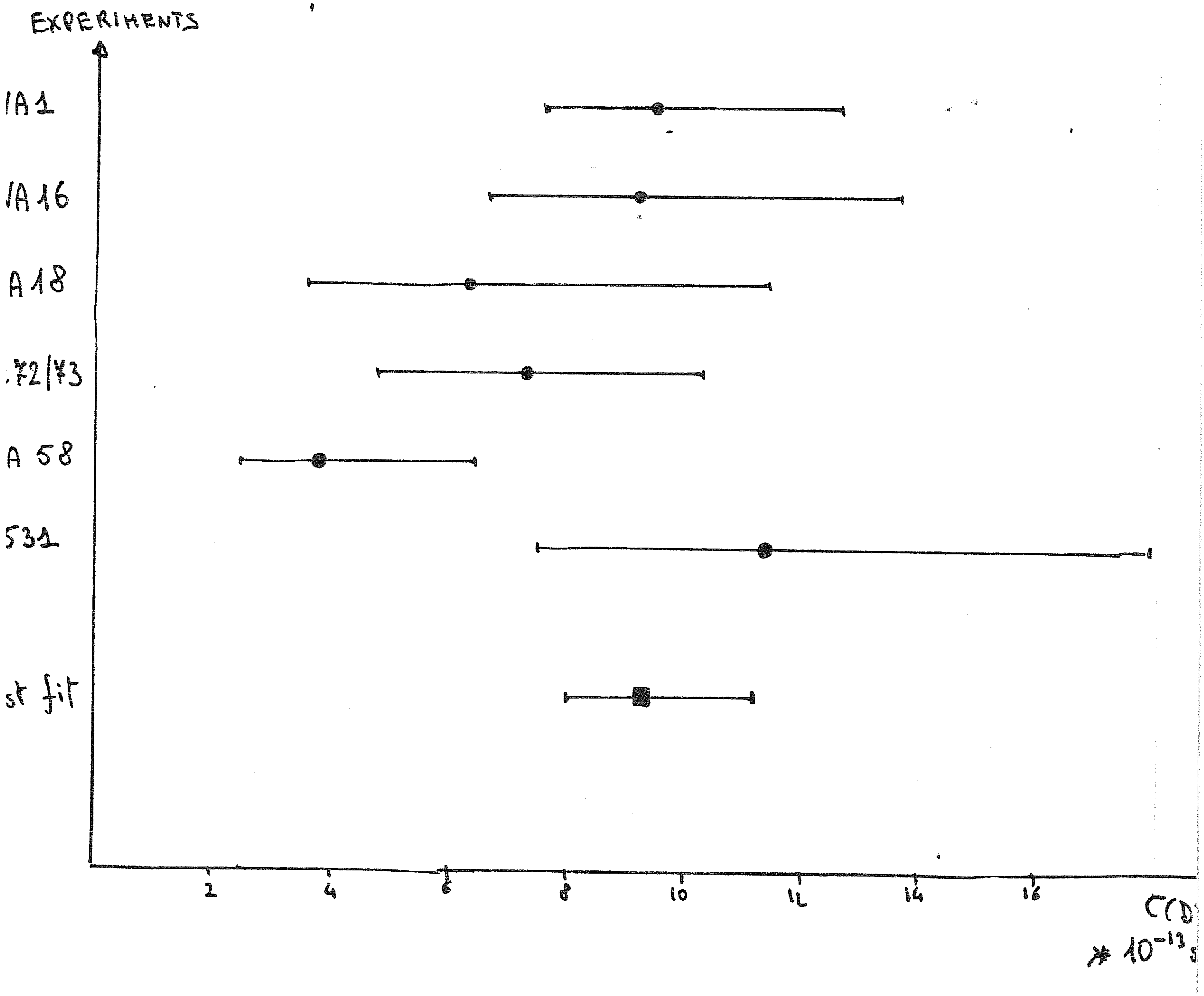
The agreement among the various experiments is good, if we exclude WA58 , which gives an excessively short lifetime, and BC72/73, for the opposite reason .

The best fit yields :

$$\tau(D^0) = \left(4.0^{+.9}_{-.7}\right) 10^{-13}\ \text{secs.} \qquad (5.3)$$

A larger statistics is, however, needed.

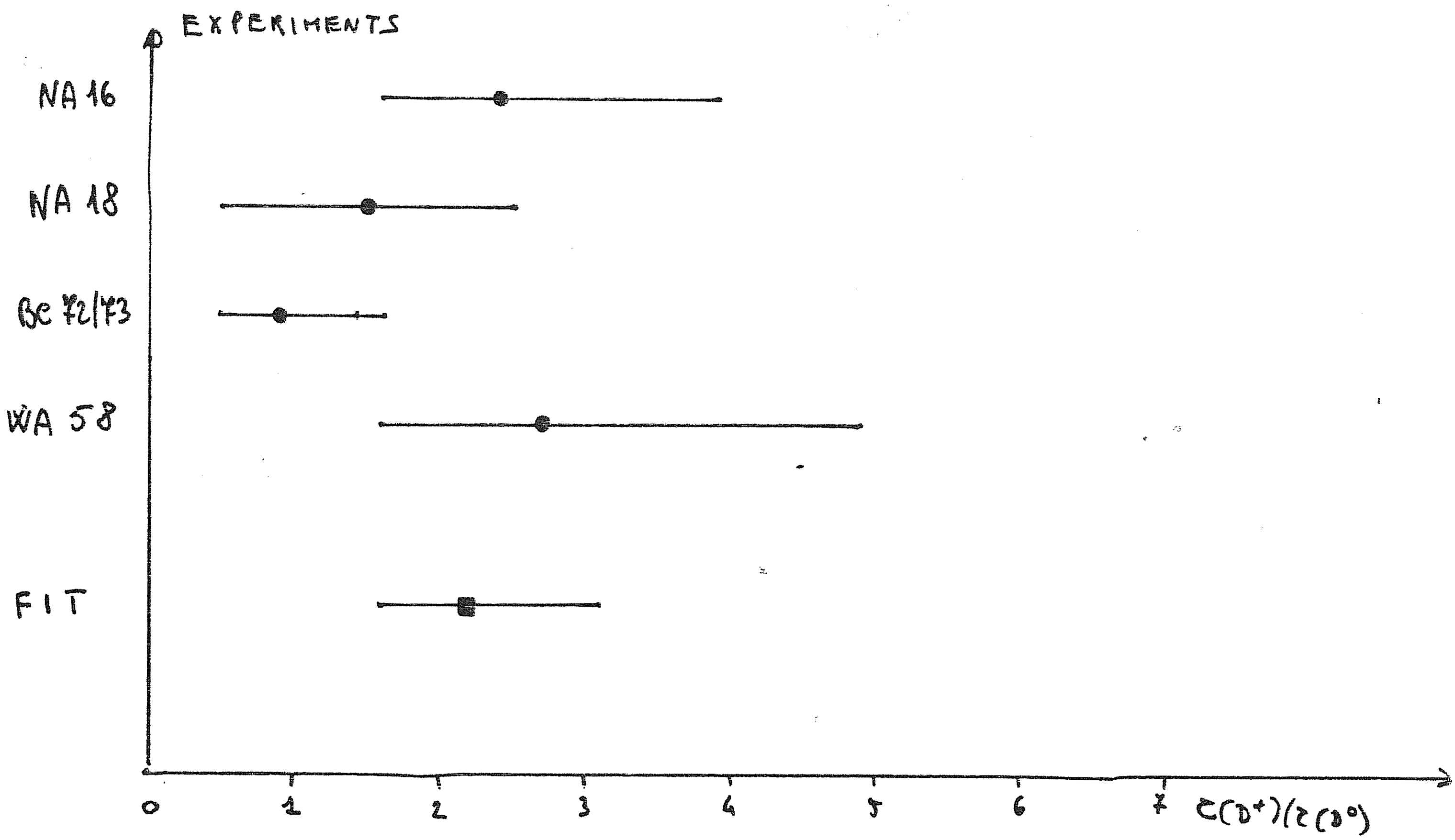
For the charged D the situation is :



The agreement is quite good (apart WA58) and the fit gives :

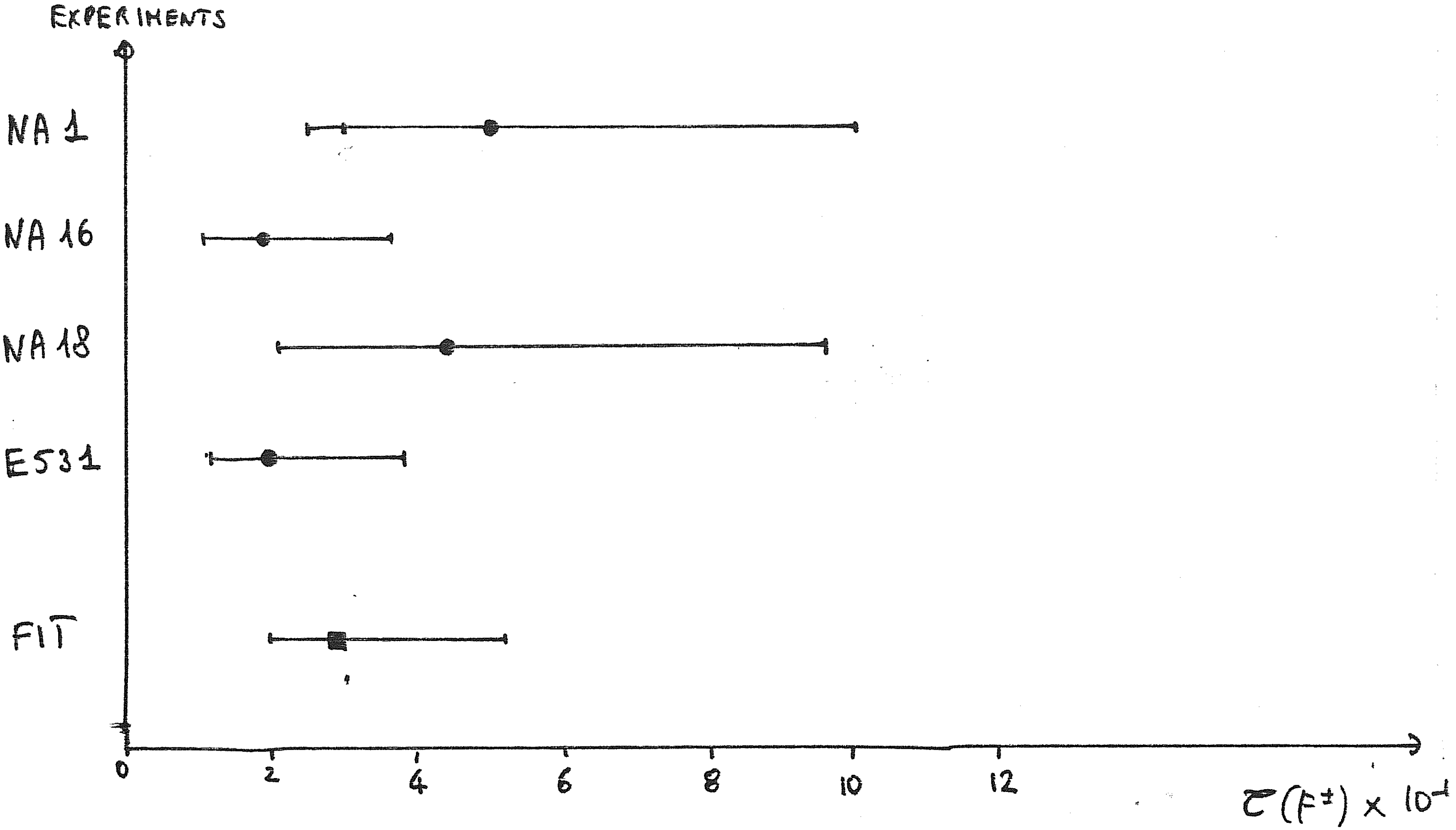
$$\tau(D^{\pm}) = \left(9.3^{+1.9}_{-1.3}\right) 10^{-13} \text{ secs.} \qquad (5.4)$$

We report the ratio $\tau(D^+)/\tau(D^0)$, from those experiments that have measured both lifetimes :



the result is : $2.2^{+.9}_{-.6}$ (5.5)

At last , we give the F results :



and

$$\tau_{(F^{\pm})} = \left(2.9 \, ^{+1.8}_{-\;.9} \right) 10^{-13} \quad \text{SECS.} \qquad (5.6)$$

(C) Comparison with theory .

(i) The best comparison between theoretical predictions and experimental data is the one concerning equation (1.19) , i.e. the prevision on semileptonic branching ratio of the charged D .

Comparing (1.19) and (5.2) :

$$19^{+3}_{-2}\ \% = 20\ \% \qquad (5.7)$$

which is really very good .

The conclusion is that the radiation graph is the most suitable for D^+ decays and that everything is consistent with 3 kinds of colours.

ii) The lifetimes of D and F (formulae 5.3, 5.4 and 5.6) are typical of weak decays. So these mesons do carry a new quantum number.

iii) In chapter 1 we made the assumption that all semileptonic widths were equal, and we deduced eq. (1.7) . The data

$$2.2^{+.9}_{-.6} \underset{\text{lifetimes}}{(\text{exp})} \quad \text{and} \quad (3.4^{+30}_{-1.7}) \left(\begin{array}{l}\text{experimental}\\ \text{branching ratios}\end{array}\right) \qquad (5.8)$$

are not in accord.

We can not say anything about this prediction, mainly because the uncertainty upon semileptonic branching ratioes is too large.

iv) The ratioes $\frac{\tau(D^+)}{\tau(D^0)}$ and $\frac{\tau(D^+)}{\tau(F^+)}$ indicate that the annihilation and exchange diagrams play an important role in the hadronic decays.

The spectator and non-spectator diagram amplitudes are of the same order of magnitude .

v) At last we calculate, from (5.2) and (5.4) :

$$\Gamma_{D^+\to e^+X} = (2.0 \pm .5)\, 10^{11}\ \text{sec}^{-1} \tag{5.9}$$

and we compare this result with eq (1.3) and (1.4) .

We argue that gluon radiation and s-quark mass effects are relevant , just in the direction indicated by Cabibbo and Maiani, although there is a little quantitative discrepancy.

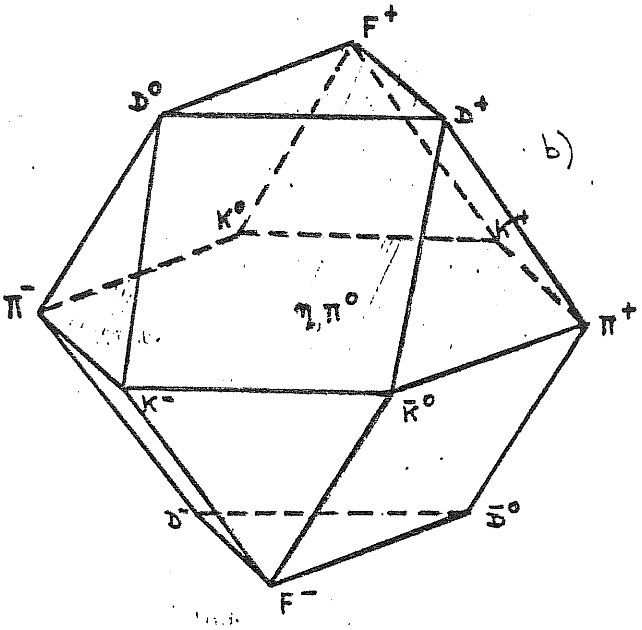


Fig. 1 The SU(4) 15 representation for mesons

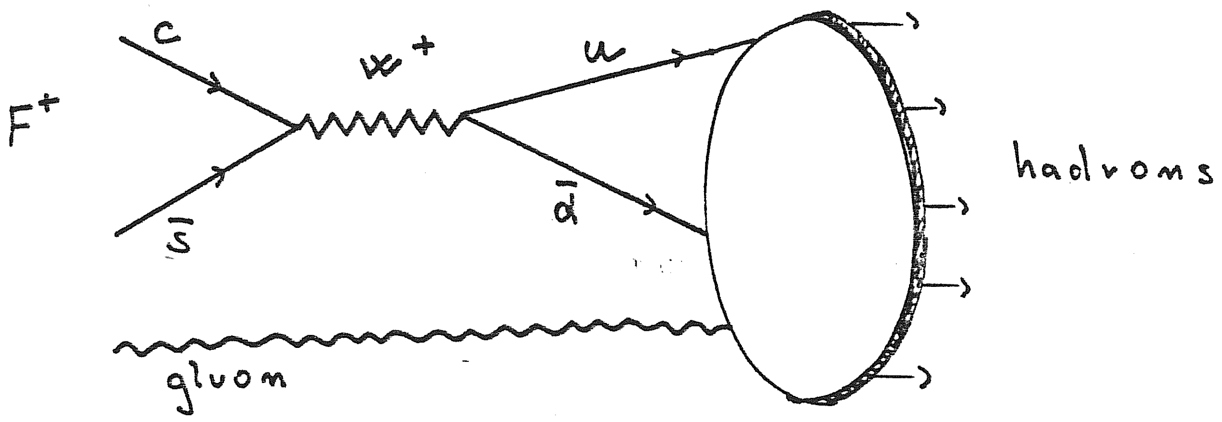


Fig. 2 Annihilation diagram with a gluon in the initial state

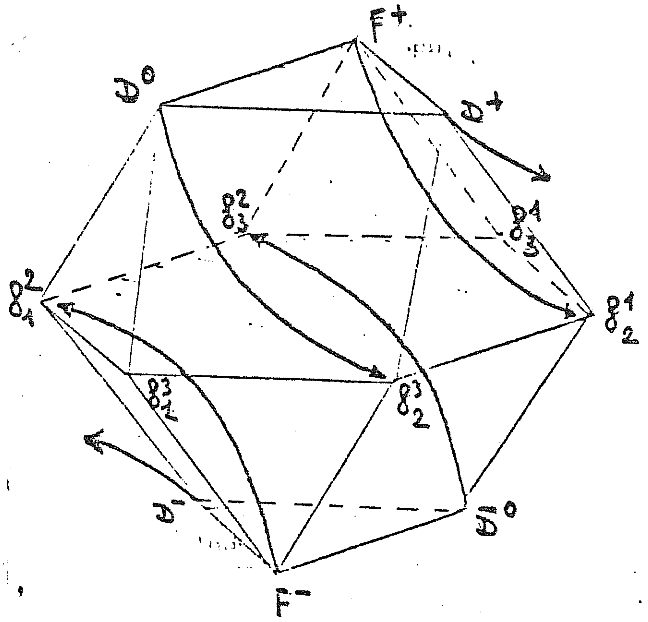


Fig. 3 Decays in the highest order in Cabibbo angle

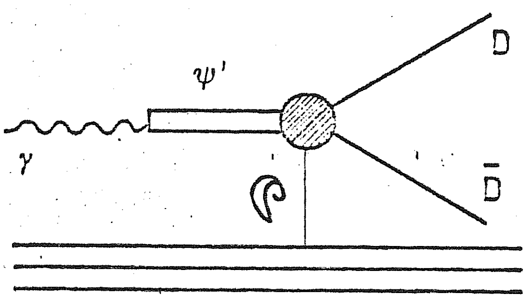


Fig. 4 Diffractive photoproduction diagram in Vector Meson Dominance theory

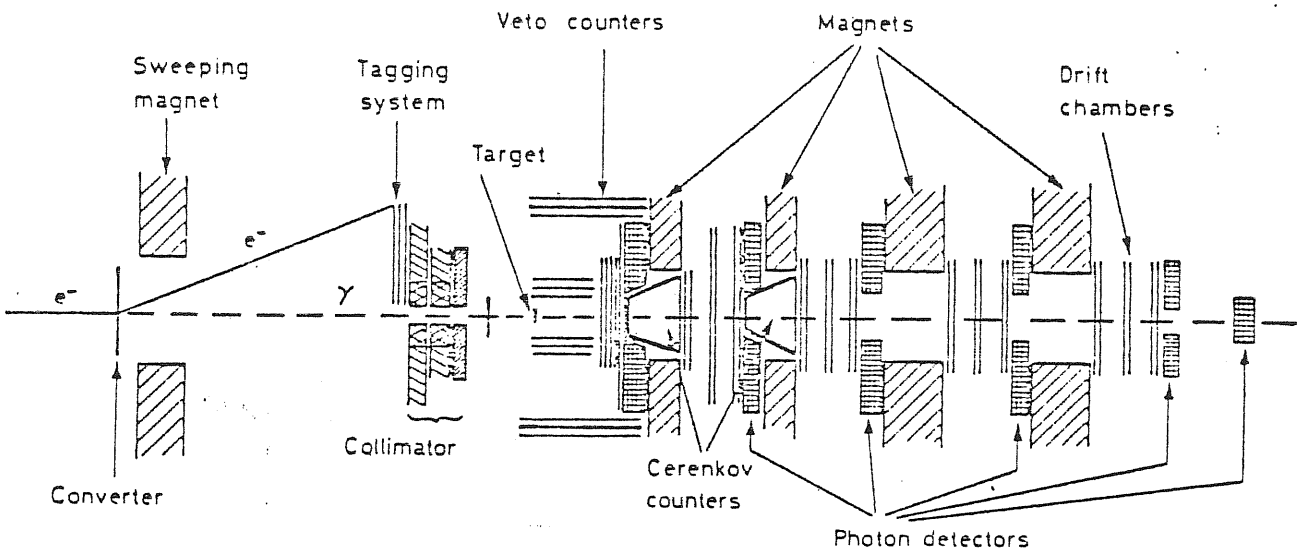


Fig. 5 The NA1 (FRAMM) spectrometer at CERN SPS .

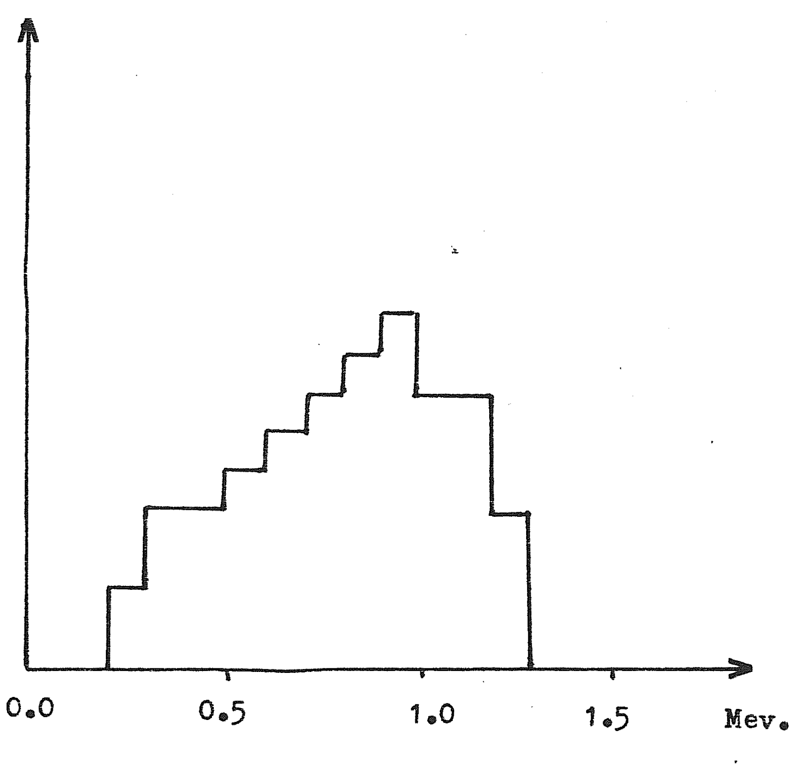


Fig. 6 Spectrum of the kinetic energy of Silicon nucleus for charmed events (Monte-Carlo simulation)

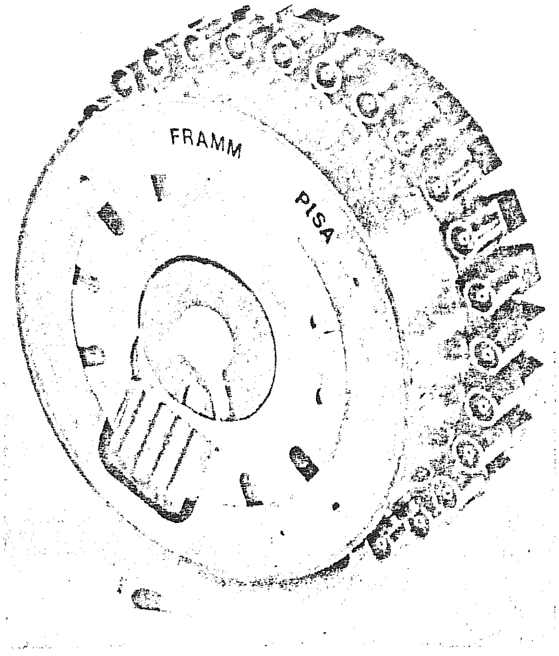


Fig. 7 External view of NA1 target.

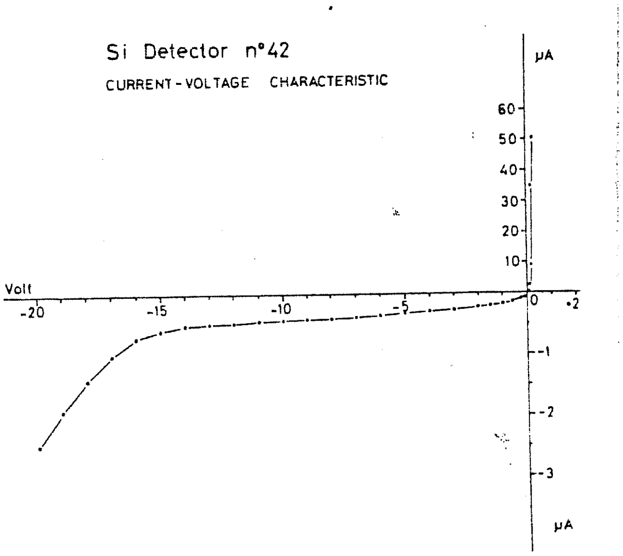


Fig. 8 Diode charatheristic of one detector of NA1 target .

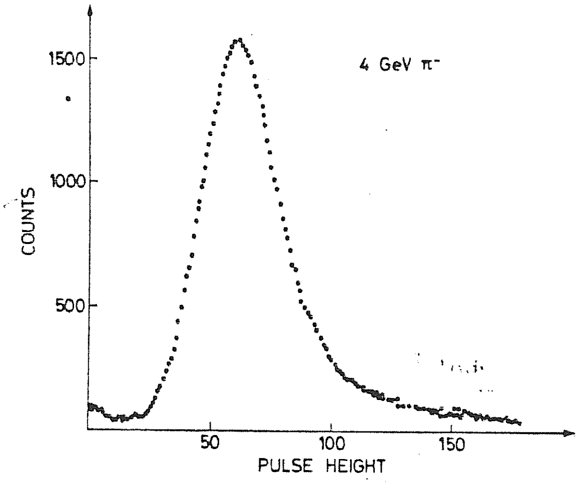


Fig. 9 Pulse hight spectrum for 4 Gev pions in one detector of NA1 target.

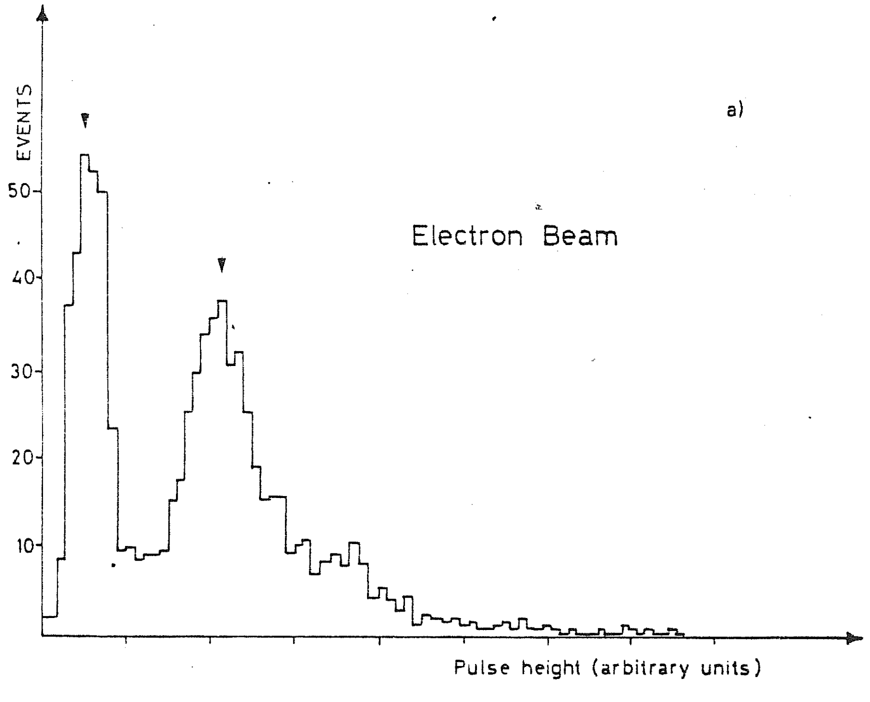


Fig. 10 Pulse hight spectrum for electron beam in one element of NA1 target .

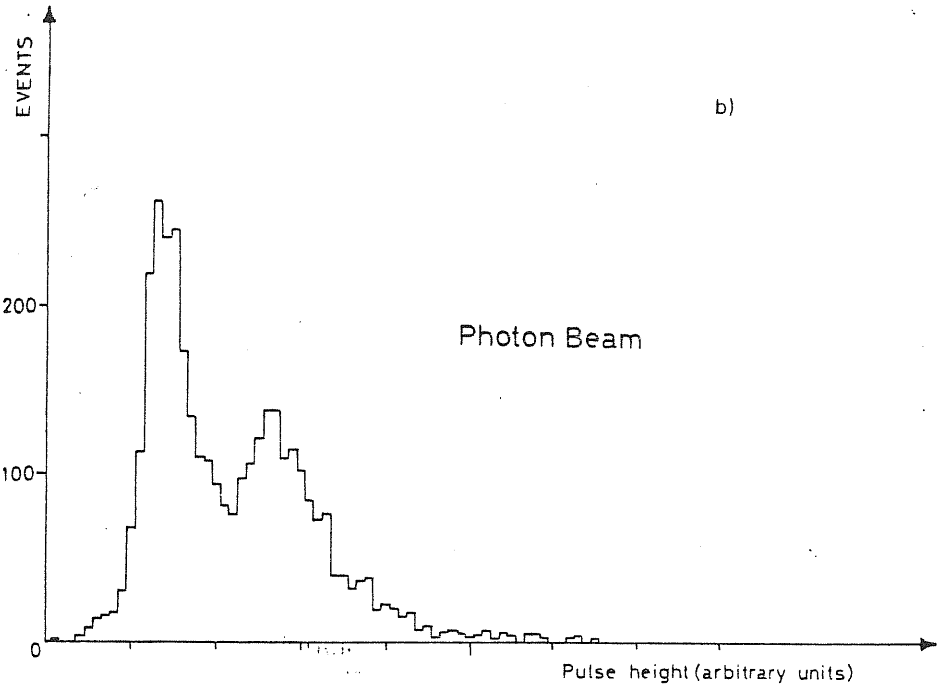


Fig. 11 v Pulse hight spectrum for photon beam in one element of NA1 target .

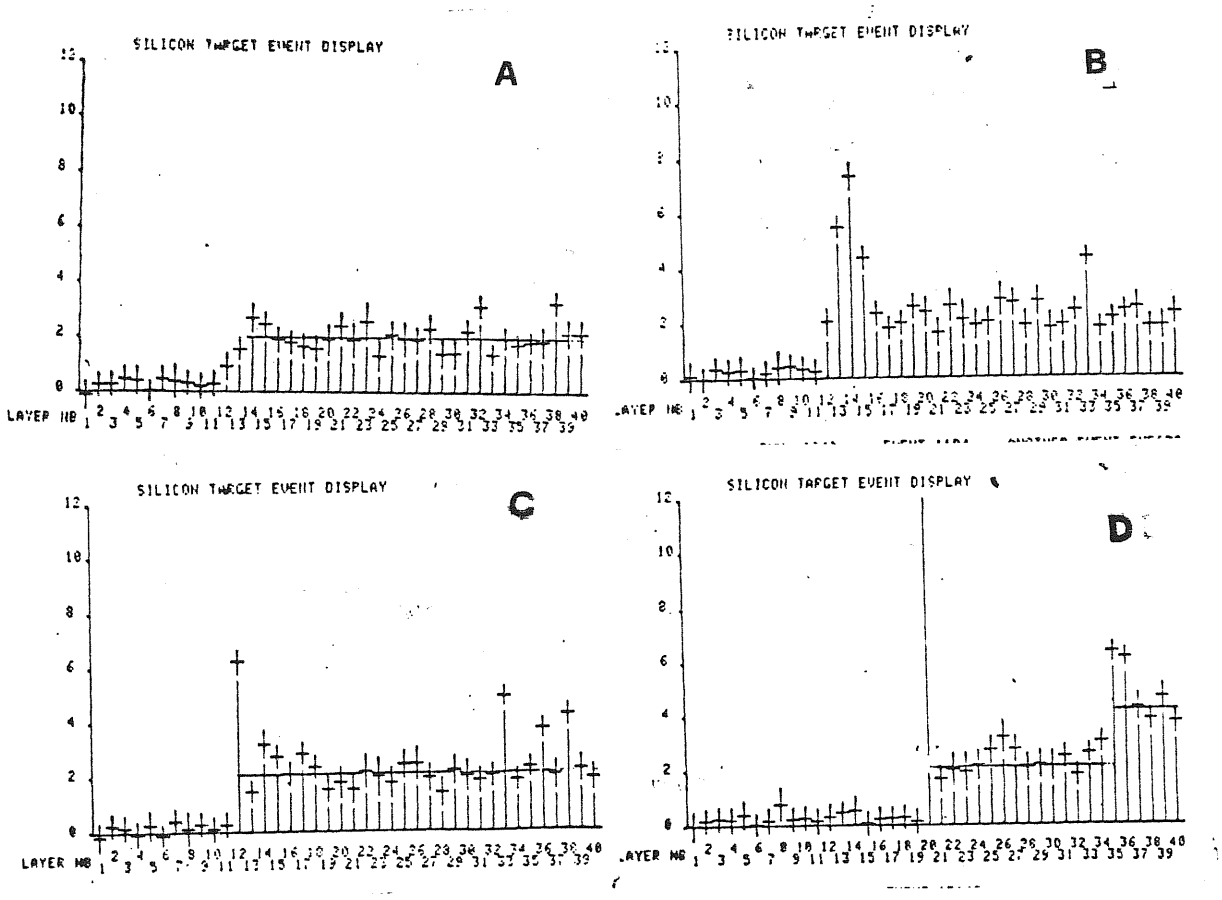


Fig. 12 typical events in NA1 target .

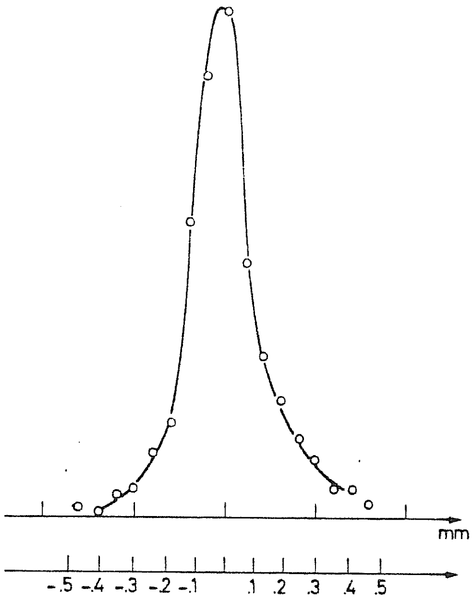


Fig. 13 Unfolded spatial resolution of sense wires , averaged over the whole sensitive area of one chamber of NA1 experiment .

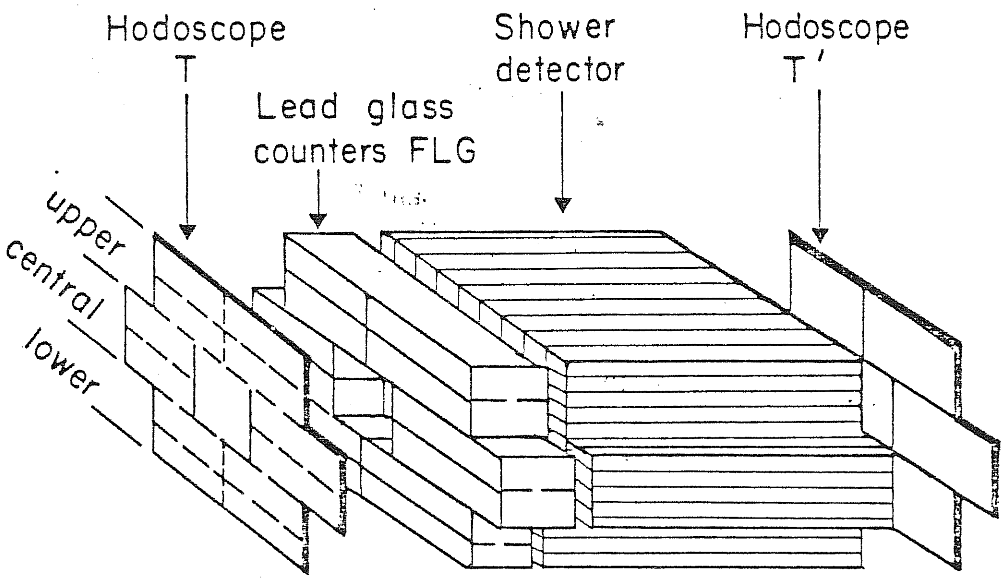


Fig. 14 Schematic view of NA1 shower detector .

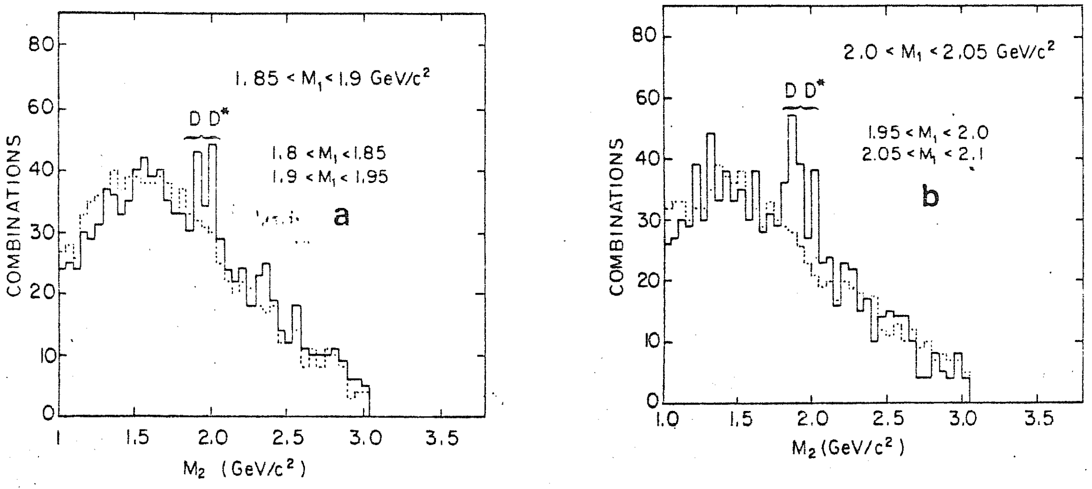


Fig. 15 NA1 experiment : the full line is the inclusive mass distribution of the D channel when a) $1.85 < M_1 < 1.90$; b) $2.0 < M < 2.05$ Gev. The dotted line is the background .

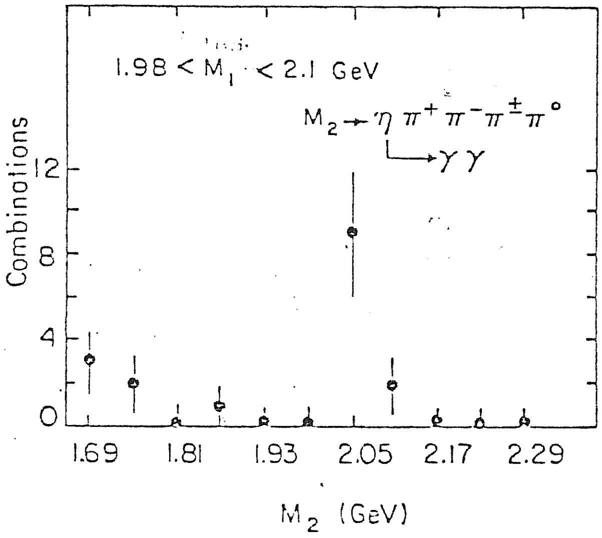


Fig. 16 NA1 experiment : invariant mass for the $\eta\pi^+\pi^-\pi^\pm\pi^0$ channel . F^- mass in the range 1.98–2.10 Gev .

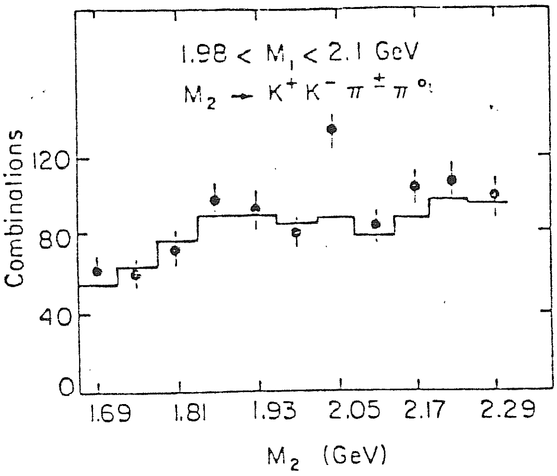


Fig 17 NA1 experiment : invariant mass for $K^-K^+\pi^+\pi^0$ channel ;
F^- mass in the range 1.98 – 2.10 Gev .

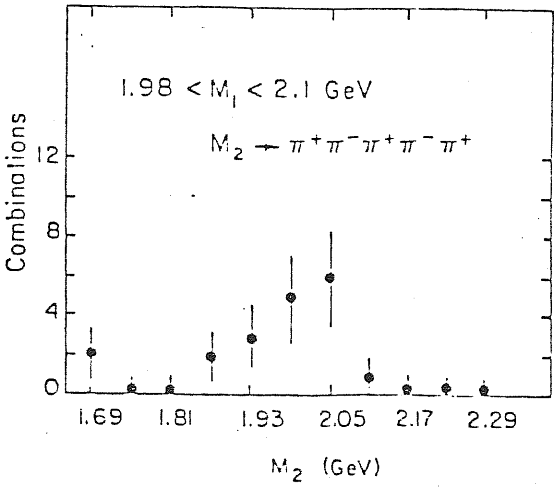


Fig. 18 NA1 experiment : invariant mass for $2(\pi^+\pi^-)\pi^+$ channel ;
F^- mass in the range 1.98 – 2.10 Gev .

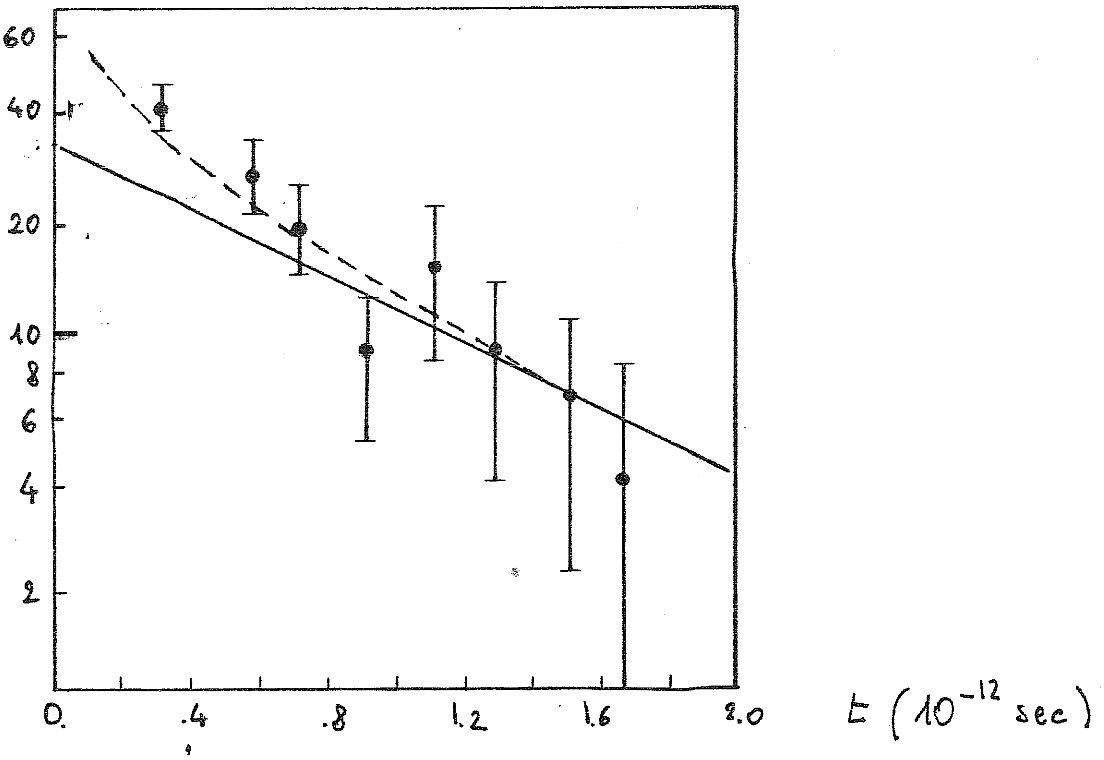


Fig 19 NA1 experiment ; time distribution of identified charmed particles decays , taking into account a 20 % D° contamination . The full line gives the $D^{\pm}$ contribution .

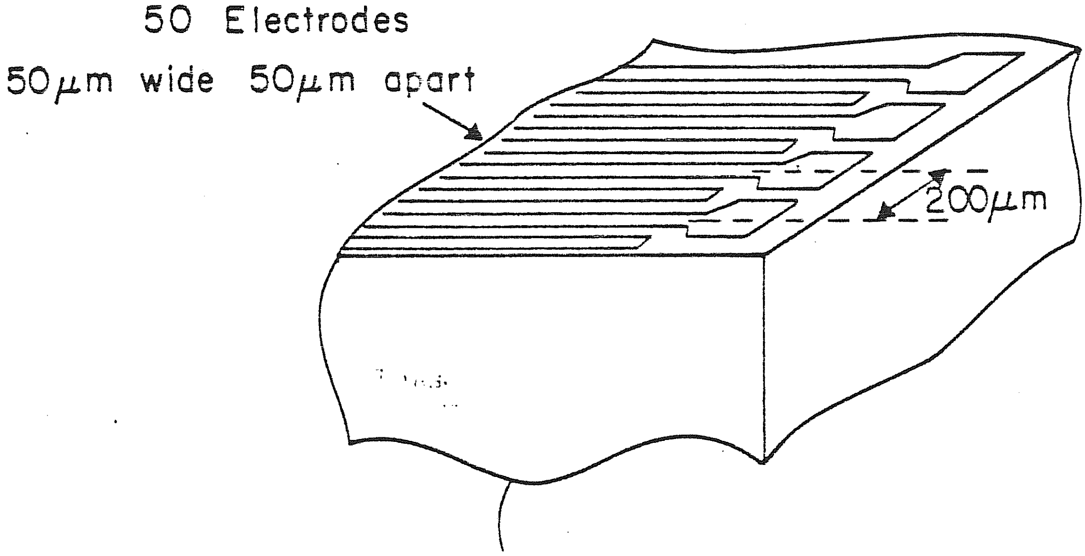


Fig 20 NA1 experiment : The new Germanium monolithic target .

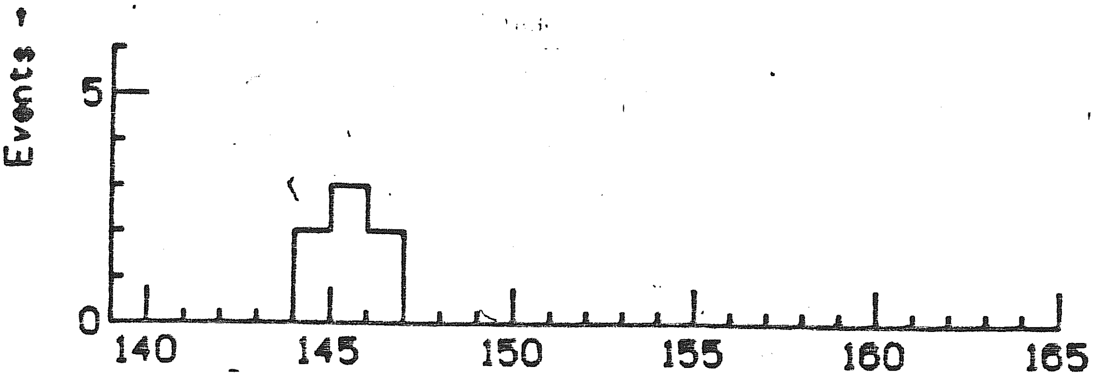


Fig. 21 MARK-II experiment : mass(D°) - mass (D°) for z .6 .

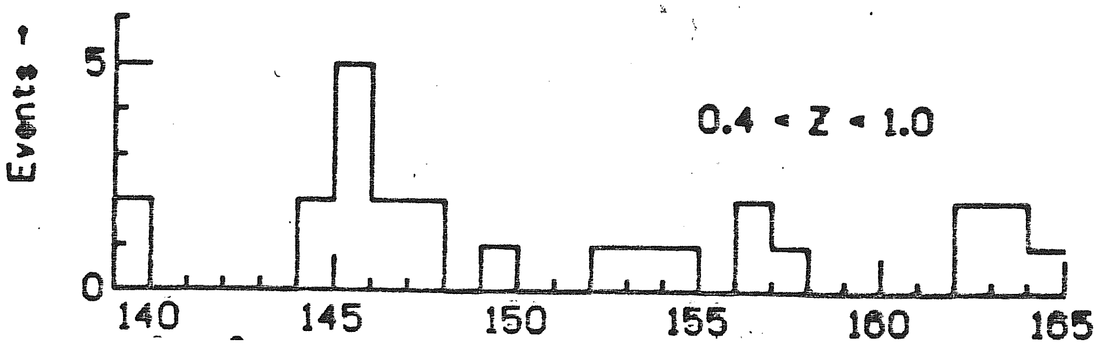


Fig. 22 MARK-II experiment : mass(D°) - mass(D°) for z .4

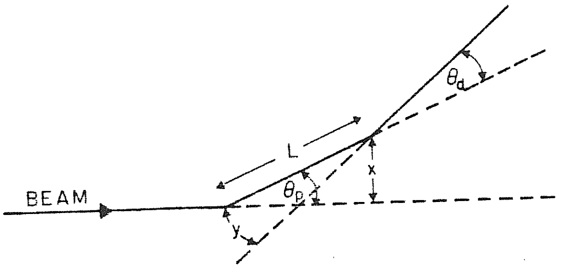


Fig. 23 relevant quantities for NA16 experiment

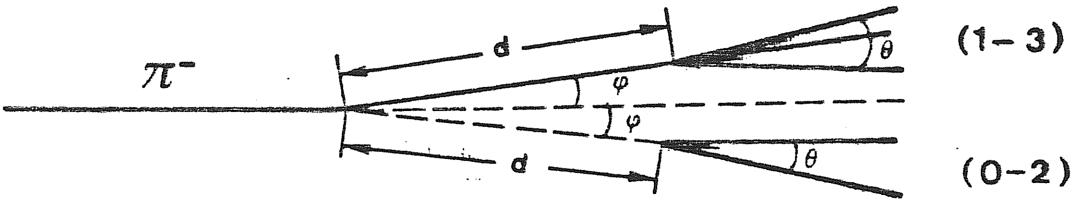


Fig. 24 definition of quantities for NA18 experiment.

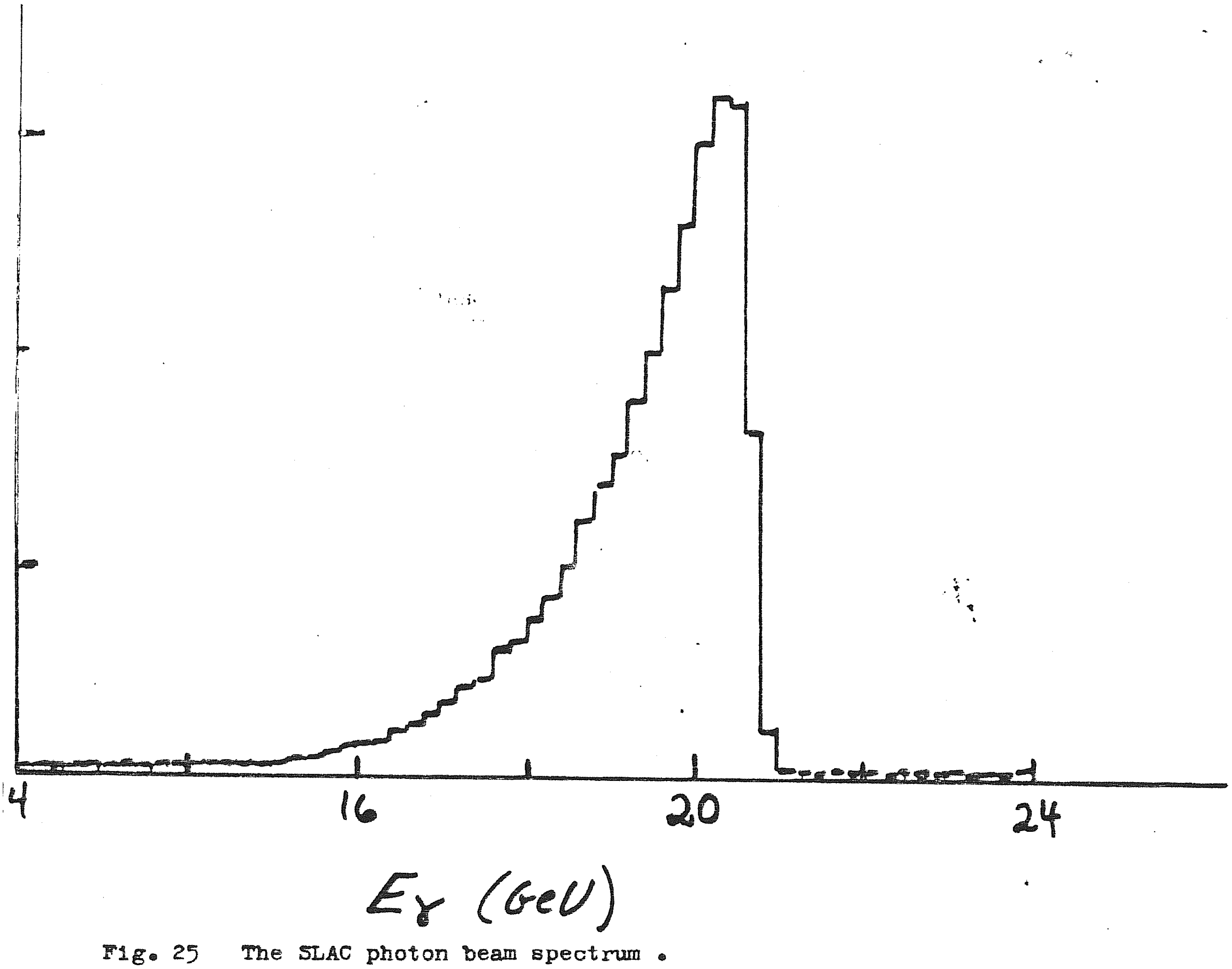


Fig. 25 The SLAC photon beam spectrum .

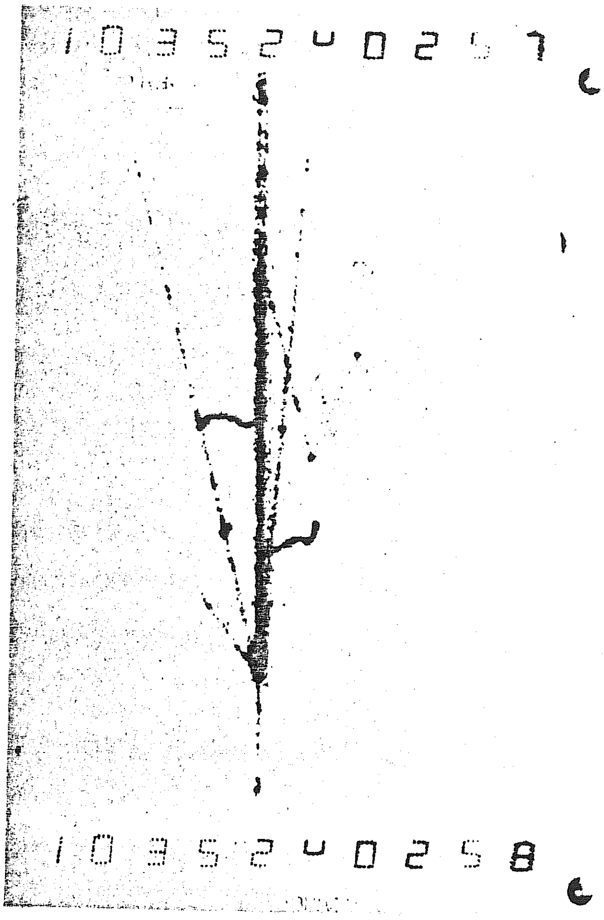


Fig. 26 a streamer chamber event.

1. Weinberg, PRL 19 (1967) 1264 ;
2. Glashow, Ilioupoulos and Maiani, PR D2 (1970) 1285 ;
3. Cabibbo and Maiani, PL 79B (1978) 109 ;
4. Bacino et al., PRL 45 (1980) 329 ; Schindler et al SLAC-PUB-2507 (1980);
5. Fritzsch and Minkowski, PL 44(1980) 455 ;
6. Rosen, PRL 44 (1980) 4 ;
7. Peruzzi et al, PRL 37 (1976) 255 ;
   Bartel et al. PL 64B (1976) 483 ;
   Goldhaber et al, PRL 39 (1977) 262 ;
   Feldman et al, PRL 38 (1976) 1313;
   Rapidis et al, PRL 39 (1977) 526 ;
   Brandelik et al, PL 70B (1977) 387;
   Bacino et al, PRL 40 (1977) 67 ;
   Feldman et al, PRL 40 (1977) 1677 ;
8. The ALEPH collaboration " To study e^+e^- annihilation phenomena at LEP" proposal to LEP committee, 25/1/1982 ;
   Amendolia et al. Nucl.Instr.& Meth. 176 (1980) 457 ;
9. Bauer et al Rev. Mod. Phys. 50 (1978) ;
10. Afek et al., Phys dept. Mc Gill University preprint;
11. Kalmus, report at the XXI conference on High Energy Physics, Paris 1982;
12. Amendolia et al. CERN/SPSC/81-91 ; and SPSC/82-33 ;
13. Amendolia et al. Nucl. Instr. & Meth. 176 (1980) 449 ;
14. Amendolia et al. Nucl. Instr. & Meth. 176 (1980) 461 ;
15. Amendolia et al. conference on experimentations at LEP, Uppsala 1980;
16. Amendolia et. al "Construction and performances of two multicell counters used in FRAMM-NA1 spectrometer" to be published in N.I.M. ;
17. Albini et al, PL 110B (1982) 339;
18. see review of particle properties;
19. Nucl. Instr. & Meth. 160 (1979) 227 ;

20. Jaros talk at XXI conf. on high energy physics, Paris 1982 ;

21. Ciapetti talk at XXI conf. on high energy physics, Paris 1982;

22. Harve et al., CERN/EF80-8 ;

2 EHS part A-B-C-D , CERN/SPSC/76-43, 76-44, 78-91, 80-50;

23. Allison et al, CERN/SPSC/80-116 ;

25. Badersthes et al, submitted to XXI conf. on high energy physics, Paris 1982;

26. Abe et al, submitted to XXI conf. on high energy physics, Paris 1982;

27. Diambrini-Palazzi, talk at XXI conf. on high energy phisics, Paris 1982;

28. Adamovich et al, PL 99B (1981) 271;

29. Allasia et al. Nucl. Phys. B176 (1980) 13 ;
Angelini et al. PL 80B (1979) 428 ;
Angelini et al, PL 84B (1979) 150;

30. Ushida et al., submitted to XXI conf. on high energy physics, Paris 1982;

31. PL 65B (1976) 299 ;
PR D19 (1979) 1287;

32. Nucl. Instr. & Meth. 167 261 ;

33. neutrino conference 1979 pag. 36;

34. PL 94B (1980) 118;

35 Sandweiss et al. PRL 44 (1980) 1104 .