



Fermi National Accelerator Laboratory

FERMILAB-Pub-80/16-EXP
7550.490

(Submitted to Phys. Rev. Lett.)

**OBSERVATION OF HADRONIC CHARM PRODUCTION
IN A HIGH RESOLUTION STREAMER CHAMBER EXPERIMENT**

J. Sandweiss, T. Cardello, P. Cooper, S. Dhawan, R. Kellogg,
D. Ljung, T. Ludlam, R. Majka, P. McBride, P. Nemethy,
L. Rosselet, A. J. Slaughter, H. D. Taft, L. Teig, and L. Tzeng
Yale University, New Haven, Connecticut 06520

and

S. Ecklund and M. Johnson
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

January 1980

OBSERVATION OF HADRONIC CHARM PRODUCTION IN A
HIGH RESOLUTION STREAMER CHAMBER EXPERIMENT[†]

J. Sandweiss, T. Cardello, P. Cooper, S. Dhawan, R. Kellogg[†],
D. Ljung[‡], T. Ludlam[#], R. Majka^{*}, P. McBride, P. Nemethy^{*},
L. Rosselet^{**}, A. J. Slaughter, H. D. Taft, L. Teig, L. Tzeng
Yale University, New Haven, Connecticut

S. Ecklund^{***} and M. Johnson
Fermi National Accelerator Laboratory, Batavia, Illinois

Abstract

Short lived particles produced in association with muons have been observed in the interactions of 350 GeV/c protons with Neon in a high resolution streamer chamber. The production and decay of these particles are consistent with the known characteristics of charmed particles and the average lifetimes must lie between 10^{-13} and 2×10^{-12} seconds. Assuming that the events are mainly D^+ mesons with lifetimes of approximately 10^{-12} seconds, the production cross section is estimated to lie between 20 μb and 50 μb per nucleon.

- † Research supported in part by the Department of Energy
- ‡ Currently at University of Maryland
- # Currently at Fermi National Accelerator Laboratory
- # Currently at Brookhaven National Laboratory
- * Currently at Lawrence Berkeley Laboratory
- ** Currently at CERN
- *** Currently at Stanford Linear Accelerator Center

The discovery of particles with the theoretically predicted attribute of charm as well as the theoretical prediction that charmed particles should have lifetimes of the order of 10^{-13} seconds^{1,2,3} have motivated a number of experiments to observe directly the decays of such particles.^{4,5,6} Several of these experiments, in particular those using bubble chamber and emulsion techniques,^{7,8} have observed such decays associated with neutrino interactions. The experiment reported here was designed to detect the production and decay of charmed particles in hadronically induced events where the production rate is perhaps as low as 0.1% of the total interaction rate. For hadronic production of charm, therefore, it is advantageous to employ a device which is triggerable with fast electronics yet retains the capability of recording short decay lengths.

A high resolution streamer chamber has been developed and used to study production of charmed particles by incident 350 GeV protons interacting with the nuclei of the chamber gas consisting of 90% Ne and 10% He at a pressure of 24 atmospheres. The chamber has been described elsewhere⁹ and we present here only a summary of its properties as shown in Table I.

Table I Streamer Chamber Parameters

Gas	90% Ne, 10% He @ 24 atmosphere
Electric field	333 kV/cm
Pulse width	.5 ns
Image intensifier	ITT Model F4112, optical gain 2500
Gap height	.45 cm
Length of visible region in beam direction	4.0 cm (Fiducial Region 3.0 cm)
Width of visible region	3.0 cm
Streamer diameter	50 μ m
Track width in space	150-200 μ m
Precision of measurement of track coordinates	40 μ m (in space).

The position of the chamber and the associated muon filter is shown in Figure 1. The experiment was set up in the M-1 beam line at FNAL tuned to 350 GeV positive particles and consisting primarily of protons. The beam was defined by the small counter B1. Upstream interactions were vetoed by requiring that the hole counters VH1 and VH2 not count for a good beam particle. The counter B2, which covered the full aperture of the entrance window assembly (about 3 cm x 3 cm), was used to reject interactions in B1 by requiring an output pulse height consistent with the traversal of a single minimum ionizing particle. Interactions of the incident beam particles in the chamber gas (or windows) were detected by requiring 2 or more counts in a small eight counter hodoscope located just behind the exit beam window. The trigger was designed to select events with prompt muons by requiring, in addition

to a beam particle and interaction signal, a count in one or more of the counters behind the muon filter and the absence of a count in the inner cone veto counter. For background studies, some data were also taken with an interaction trigger which required only a beam particle, an interaction and no inner cone veto. Table II summarizes the data sample obtained.

Table II Data Sample

Incident beam	350 GeV protons
Incident flux per pulse	$(.5 \text{ to } .8) \times 10^6$
Average number of triggers per pulse	- 1
Number of fiducial interactions with full muon trigger	1062
Number of fiducial interactions with interaction trigger	255
Ratio of non fiducial to fiducial triggers	10/1

The scaled, ungated rates for beam, interaction and muon triggers imply that the muon requirement rejects all but 1 in 2200 hadronic interactions and, if hadrons accompanying charm production are distributed in a manner similar to those produced in ordinary hadronic interactions, that approximately 27% of charm production events survive the cone veto requirement. Using these rates, a Monte Carlo analysis discussed below using different assumptions for charmed particle semi-leptonic branching ratios and lifetimes indicates that the muon trigger events obtained are between 15 and 50 times richer in charm production than a similar sample of "raw" interaction trigger events. Each

fiducial interaction was measured on an image plane digitizing system with a resolution (in space) of 12 μm . Events in which one or more tracks clearly did not originate at the primary (production) vertex made up the final sample which was analyzed as follows.

Because of the "large" track width, 150-200 μm , this experiment is primarily sensitive only to those decay tracks which have the largest angle relative to the incident beam direction. It is therefore convenient to analyze the data sample in terms of an l, θ_D plot. The distance l is the distance in space (neglecting dip angles) which the charmed particle traveled before decaying and θ_D is the projected angle of the decay track. When the line of flight of the charmed particle cannot be observed it is assumed to be along the beam direction. These definitions are illustrated in figure 2. The boundary separating the "charm" region and the "strange particle" region was chosen so that for charmed particle lifetimes of 10^{-12} sec. or less there should be a negligible number of charmed particle decays in the strange particle region. It is important to note that this boundary is determined solely by kinematics and does not depend on assumptions about the dynamics of hadronic charm production. Finally, a requirement is imposed on all but the "short decay" events that the projected production angle of the decaying track be within 13° of the incident beam direction if the event is to be considered a charm candidate. This rejects many strange particle events but very few if any charm events, since at $\theta = 13^\circ$, $P_\perp = 5.9 \text{ GeV}/c$ for a D meson with $X_F = 0$.

Figure 2 presents the data from the muon trigger sample and shows that there are 10 charm candidate events. The sources of background in this sample include delta rays, secondary interactions and strange particle decays. While delta rays can be shown to give a negligible contribution and secondary interactions amount to less than 0.2 background events, strange particle decays are a potentially serious source of background. From the events observed in the strange particle region, the strange particle decay contributions for those strange particles with momenta less than about 2 GeV/c can be directly estimated. Above 2 GeV/c, where at typical decay angles the potential path for decay of these particles is largely inside the charm region, the background has been estimated using data from a bubble chamber study of 205 GeV/c π^- on hydrogen.¹⁰ The bubble chamber data is also in good agreement with the number of events in the strange particle region of the t, θ_D plot. In carrying out the estimates of the fast strange particle and interaction background certain simplifying assumptions have been made which have the effect of overestimating the background. A summary of the charm signal statistics is given in Table III. It should be noted that, based on the scintillator latches, for two of the charm candidate events the decay track is the only track which could have been the trigger muon. In two other charm candidate events the decay track was possibly but not uniquely a muon.

Table III Charm Signal Summary

Trigger category	Strange particle events	Charm candidates
Muon trigger	26	10
Interaction trigger	8	1

Backgrounds to charm candidates

	Muon trigger	Interaction trigger
"Slow" strange particles	$1.07 \pm .38$	$.26 \pm .09$
Fast strange particles	.85	.20
Secondary interactions	.18	.04
Total	$2.1 \pm .4$	$.5 \pm .1$

This experiment has observed a definite signal in the muon trigger events which cannot be explained by background. While the experiment cannot of itself prove that this signal is due to charm production, the muon association and the lifetime range involved made this a reasonable and self consistent conclusion. In order to extract the charmed production cross-section and lifetime, the net detection efficiency was determined for a particular production model and for two different decay models applied to a Monte Carlo sample generated from the observed events.

The charm production model which was used assumed that D , \bar{D} pairs were produced in an uncorrelated fashion with the following Feynman X (X_p) and transverse momentum (P_{\perp}) dependence.

$$\frac{d^2\sigma}{d(P_{\perp}^2)dX_F} = Ae^{-9.94X_F^2 - 2P_{\perp}}$$

The results are essentially unchanged if an X_F distribution of the form $(1-X_F)^{2.9}$ is used as suggested by studies of prompt single muons.¹¹ Similarly, including a correlation term of the form¹¹

$$M^3 \frac{d\sigma}{dM} = e^{-.55M}$$

where M = effective mass of the D, \bar{D} pair in GeV, has little effect on the results since, with the resolution of this experiment, essentially only one of the charmed particles was detected. It is also assumed that the states D^+D^- , $D^+\bar{D}^0$, $D^0\bar{D}^0$ and D^0D^- are produced with equal probability and that the purely hadronic decays of the D mesons proceed via phase space with the multiplicities adjusted so that the average number of charged decay particles from both charged and neutral D mesons is 2.3. Finally, the following two models have been used for the semi-leptonic branching ratios and the ratio of D^0 to D^+ lifetimes:¹²

$$\text{Model 1: } BR(D^0) = BR(D^+) = 10\%; \quad \tau(D^0) = \tau(D^+)$$

$$\text{Model 2: } BR(D^+) = 23\%; \quad BR(D^0) = 0\%; \quad \tau(D^0) = \tau(D^+)/5.8$$

The use of 0% for $BR(D^0)$ rather than the ~ 4% required by the theory of charm decays is for computational simplicity and is not significant at the level of statistics in this experiment. Assuming that charm events are lost because of the cone veto requirement at the same rate as ordinary hadronic events, the efficiency of this experiment for detecting charm decays as determined by the Monte Carlo program above together with the measured rejection factor for ordinary hadronic interactions determine an enhancement factor F for muon trigger

selected events. The charm production cross section is then given by

$$\sigma_c = 30\text{mb} \times \left(\frac{N_{\text{charm}}}{FN_{\text{total}}} \right)$$

where N_{charm} is the number of charm events observed and N_{total} is the total number of interactions observed.

The results of this analysis are shown in Figure 3. Points are shown for the two models discussed above as well as for Monte Carlo calculations assuming two lifetimes for the D^\pm , namely 5×10^{-13} sec. and 10^{-12} sec. In this general region the relationship between production cross section and assumed lifetime yielding the observed signal is approximately linear as indicated. Limits on the lifetime may be deduced by noting that if the lifetime were less than 10^{-13} sec the observed events would have clustered at the lowest values of θ and θ_D permitted by the scanning efficiency. On the other hand, if the lifetime were greater than 2×10^{-12} sec. the method of background determination used would have eliminated the signal in the charm region.

In conclusion, short lived particles produced in association with muons in hadronic interactions have been observed in this experiment. The most reasonable interpretation is that of charmed particle production. The average lifetime of the particles observed above the strange particle background must lie between 10^{-13} and 2×10^{-12} seconds. If as suggested by references (11) and (12), the lifetime of the D^\pm is approximately 10^{-12} seconds, the production cross section is estimated to lie between 20 and 50 μb per nucleon for 350 GeV incident protons.

The development and utilization of the High Resolution Streamer Chamber would not have been possible without the skill and dedication of many people. We are especially appreciative of the support and assistance of the research division and meson laboratory division of FNAL in the entire process of building the chamber and setting up and running the experiment.

- ¹ M. K. Gaillard, B. W. Lee and J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).
- ² J. D. Jackson, C. Quigg and J. L. Rosner, Proc. 19th Int. Conf. High Energy Physics, Tokyo (1978).
- ³ N. Cabibbo, G. Corbo and L. Maiani, Nucl. Phys. B155, 93 (1979).
- ⁴ K. Niu, E. Mikumo and Y. Maeda, Progr. Theoret. Phys. 46, 1644 (1971).
- ⁵ G. Goldhaber et al., Phys. Rev. Lett. 37, 255 (1976).
- ⁶ H. Fuchi et al., Phys. Lett. 85B, 135 (1979).
- ⁷ R. Diebold, Proc. 19th Int. Conf. High Energy Physics, Tokyo (1978).
- ⁸ N. W. Reay, Proc. Symp. Div. of Parts and Fields, Montreal (1979).
- ⁹ J. Sandweiss, Physics Today, Oct. (1978) and R. Majka et al.; Nucl. Inst. and Meth. (to be published).
- ¹⁰ D. Ljung, Private Communication.
- ¹¹ K. W. Brown et al., Phys. Rev. Lett. 43, 410 (1979).
- ¹² J. Kirby, Int. Symp. Lepton and Photon Interact., FNAL, Aug. (1979).

1. The experimental arrangement, including the streamer chamber, beam defining counters, interaction hodoscope and muon filter.
2. Definitions of event categories and data from the muon trigger sample displayed on a plot of length vs. laboratory angle. The squares represent all events having projected production angle $\geq 13^\circ$. Open circles represent events for which the track not associated with the primary vertex is possibly but not uniquely a muon. The two triangles represent events for which this "decay track" is a uniquely identified muon.
3. The relationship between the charm production cross section and the lifetime of the D^+ implied by this experiment, for the two assumptions discussed in the text.

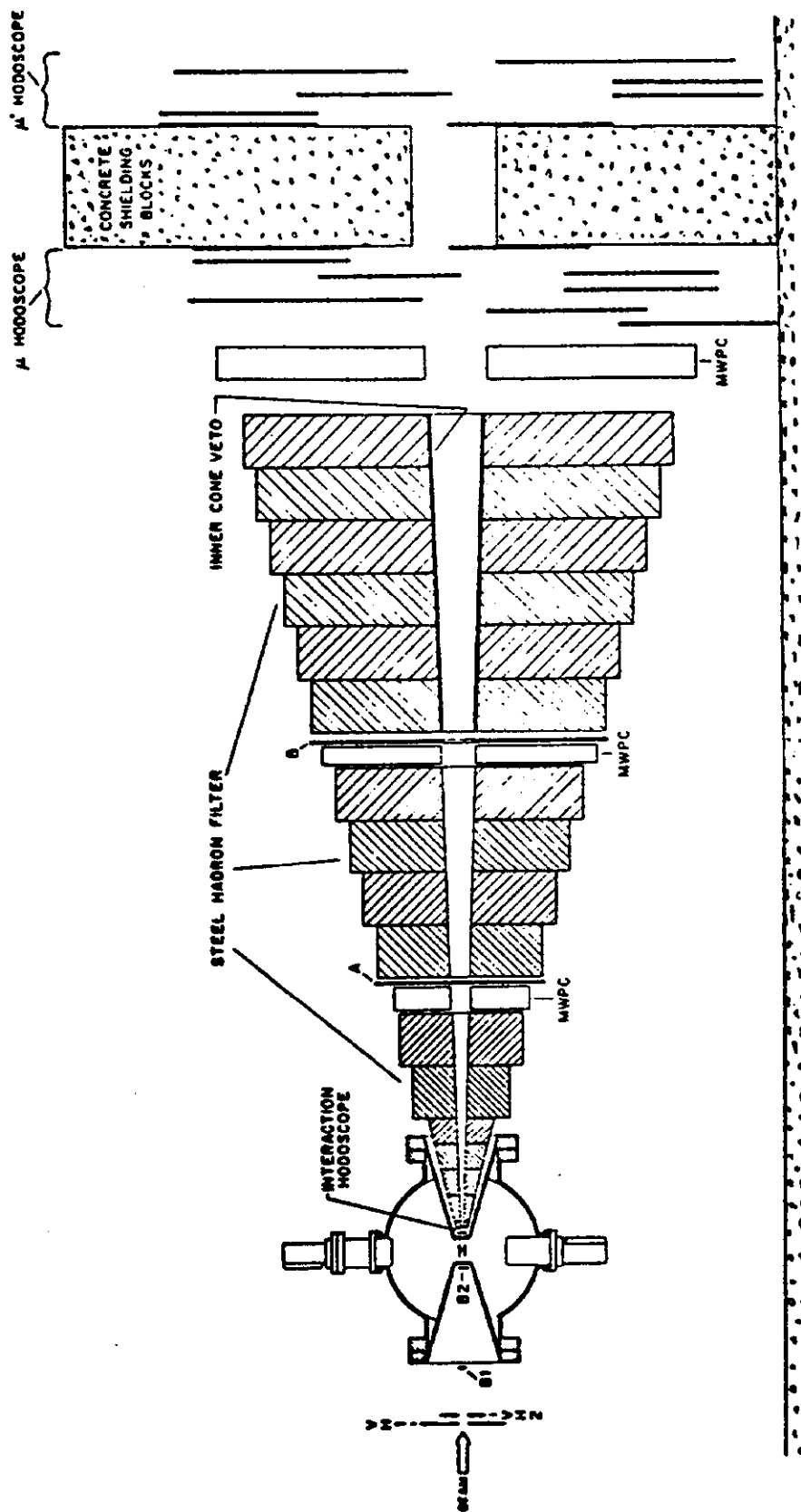


Fig. 1

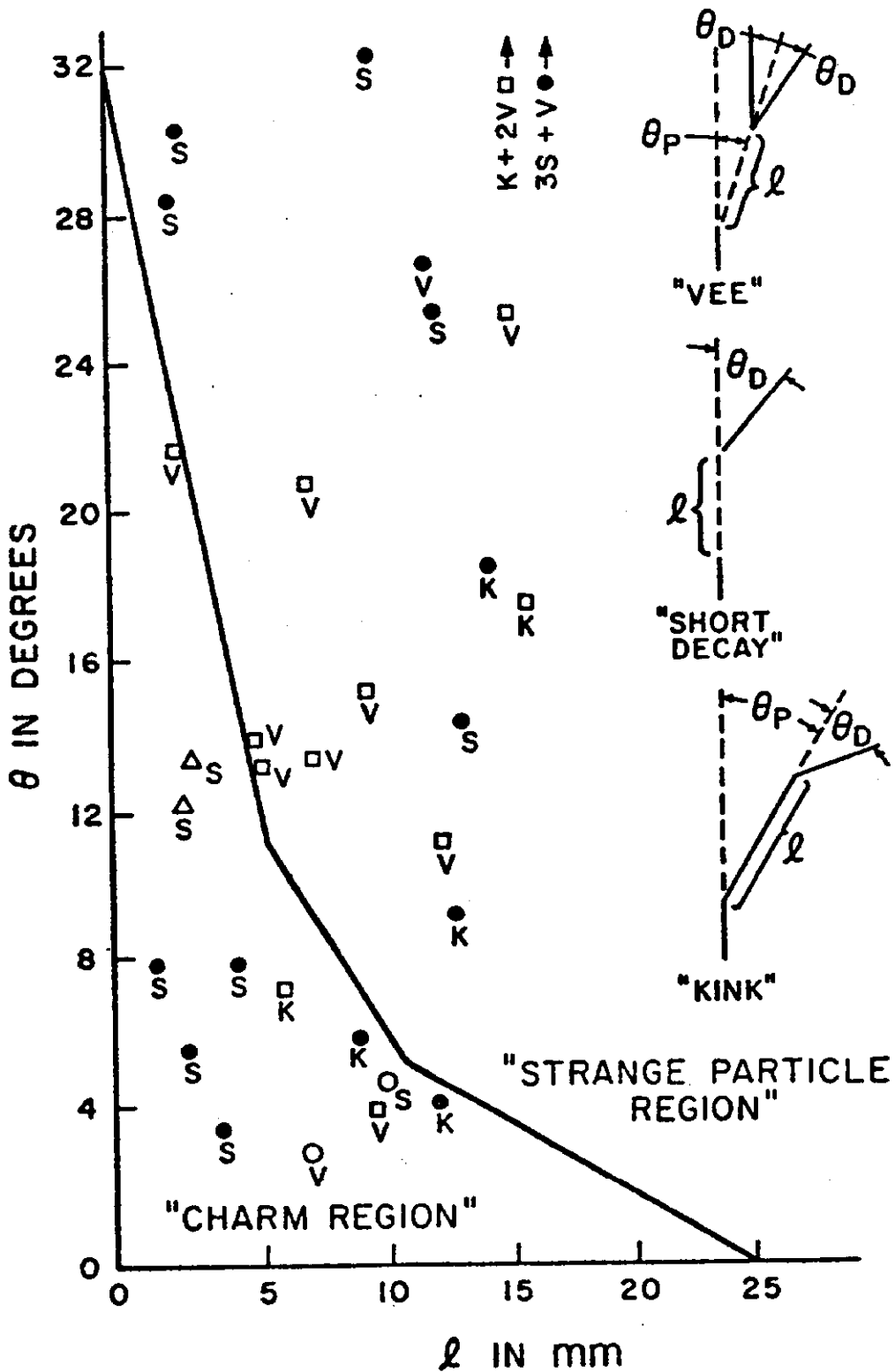


Fig. 2

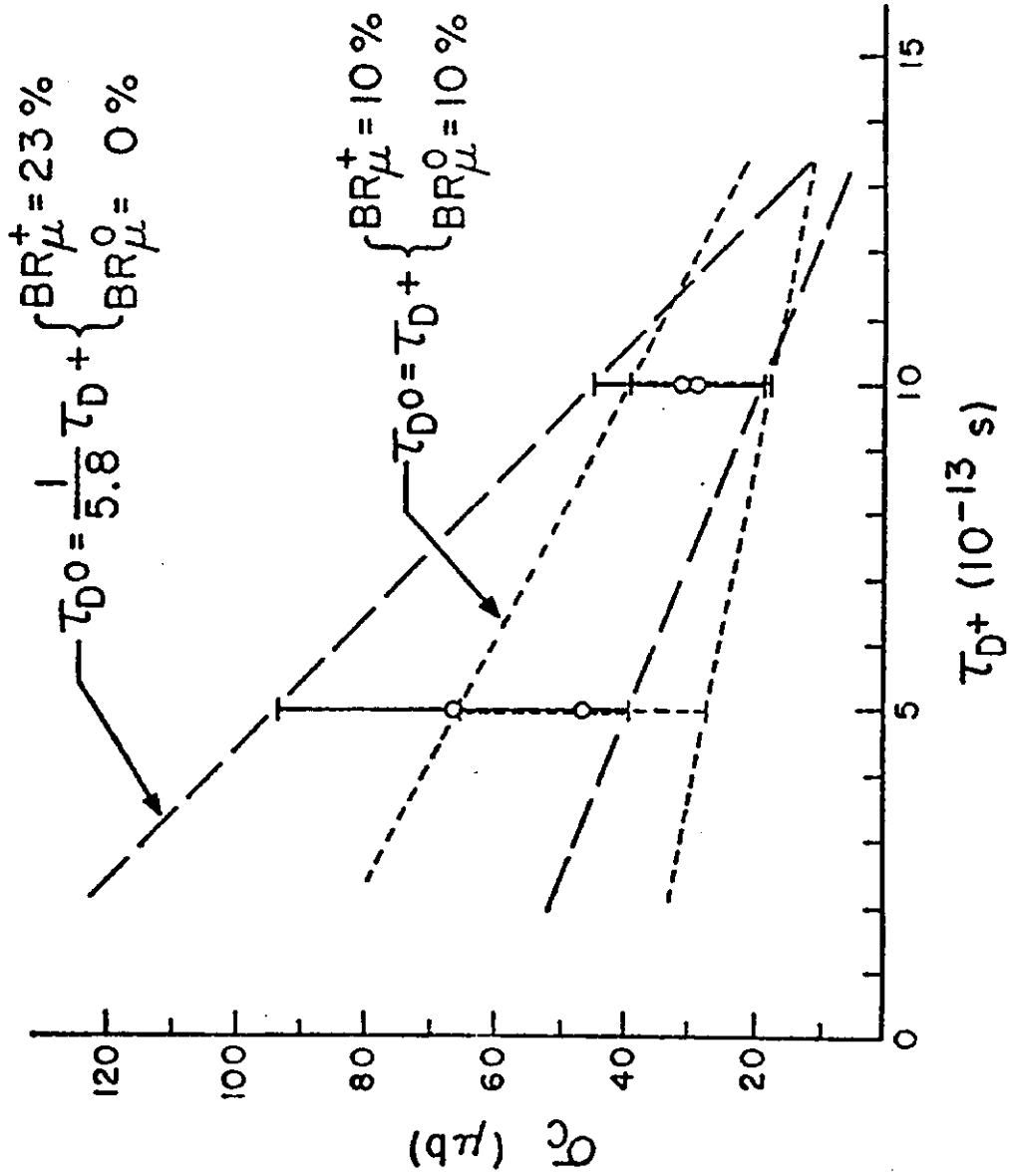


Fig. 3