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AN ATTEMPT TO DETECT PARTICLES OF VERY SHORT LIFE-TIMES PRODUCED IN HIGH ENERGY NEUTRINO INTERACTIONS

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A sample of 28 high energy neutrino interactions have been carefully measured in emulsion in order to detect particles of very short life-times. Such particles, if produced in the interactions, would have been detected with high efficiency if $\tau \gtrsim 5\times10^{-15}$ s.

There is now experimental evidence[1] that charmed hadrons exist with masses around 2 GeV/c^2. Theories suggest for these particles mean life-times in the range 10^{-12}-10^{-14}s, or even less. Particles with such short life-times are at present directly observable only if both production and decay occur in nuclear emulsion.

The aim of this work is to extend the limit of detectable flight paths down to very short values, beyond those easily recognizable by eye ($\sim$5 to 20μm, depending on the topology).

The experimental technique is already known and has been used, for instance, by H.Shwe et al.[2] for a measurement of the π^0-meson mean life-time. The method consists in measuring with high accuracy the coordinates, projected onto the

emulsion plane, of the grains of the minimum ionization tracks emerging from a star, all them within the same field of view, and in reconstructing the interaction point, together with its uncertainty of location, by means of a fitting procedure.

A sample of 28 interactions on emulsion nuclei, produced by a wide band neutrino beam at Fermilab and found in a previous experiment[3,4] have been analyzed.

The direction of motion of the incoming neutrinos lies in the emulsion plane and the average multiplicity of minimum ionization tracks produced in the interactions is ~6. Neutrino interactions were preferred to hadron ones both because of the higher expected charm production rate and also for the broader angular distribution of minimum ionization tracks.

Depending on the decay mode, an unstable particle could manifest itself with different characteristics, nevertheless experimental evidence of its decay will be obtained if at least one track does not point to the origin determined by the others. If more tracks do not converge the evidence becomes stronger.

The events were measured on a Koristka R4 microscope with 100x or 53x objectives, digitized micrometric eyepieces (sensitivity, 1 div = 0.023 μm and 0.045 μm respectively); the output was directly punched on cards.

No attempt was paid to measure z coordinated due to the much smaller sensitivity.

Three "reference" grains were measured at the beginning and at the end of each track, and this allowed the coordinates of each grain to be corrected for possible systematic drifts during the measurement. They usually occur due to differential thermal expansions and are easily lowered, by taking appropriate care, to 0.03 μm/min or less (typical values around 0.01 μm/min).

The reproducibility of the coordinates of a single grain,

evaluated from the measurements of the reference grains, turned out to be only slightly larger than the instrumental sensitivity. In fact:

obj. 53x $\sigma_x \simeq \sigma_y \simeq 0.047\ \mu m$

" 100x $\sigma_x \simeq \sigma_y \simeq 0.028\ \mu m$

Each track was fitted to a straight line by means of a least squares procedure assuming an equal error in determining both x_i and y_i of each grain.

The dispersion of grains around the fitted line was $\sim 0.06\ \mu m$ (r.m.s.), ranging from 0.03 to 0.10 μm. No correlation was found between dispersion and azimuth, dip angle, measured length and number of grains. Therefore possible effects due to instrumental biases, multiple scattering, spurious scattering or distortion are negligible in our conditions.

Once all the tracks of an event were fitted the "vertex" and the r.m.s. errors on its coordinates are computed searching for the point of minimum distance to all the tracks (weighted with their errors). This procedure provides an estimate of the dimensions of the uncertainty zone: typical r.m.s. values are 0.05 to 0.10 μm across the beam, 0.1 to 0.5 μm along the beam.

In order to check if one or more tracks do not converge to a common origin, they were alternatively removed from the event, and their projected distances to the "vertex" defined by the others computed. Fig. 1 shows a map of the distances vs. the pulls (distance/error) for our sample. The distribution of the pulls obtained is found to be nearly Gaussian with unit standard deviation. The tracks show a close correlation between distances and pulls with the exception of a few cases, $\sim$10% of the total, due to anomalous measuring conditions

(first measurable grain very far from the star centre, very few grains in the field, superposition with other tracks, etc.).

If we assume that a decaying particle can be detected if at least one of the emitted tracks misses the vertex by more than 3 standard deviations, we can deduce from Fig. 1 that our sample does not contain candidates for short path decays. A lower limit to the projected distance in order to get evidence of a decay is $\Delta_{min} \simeq 0.17 \mu m$, and includes $\sim 97\%$ of the measurements.

Obviously from this value we could deduce information on a particle's life-time if both its nature and decay schemes were known. Hereafter we will confine ourselves only on D charmed mesons decays and compute their detection probability P as a function of the mean life-time τ and velocity β. A Montecarlo decay simulation was performed assuming an energy distribution among the decay products in the c.m.s. according to their relativistic phase-space and considering the decay as detectable if at least one of the charged products has $\Delta_{proj} \gtrsim \Delta_{min} = 0.17 \mu m$.

The detection probability $P(\tau)$ turns out to be nearly independent on the decaying particle velocity β since the opposite effects on Δ of the narrowing of lab emission angle and of the lengthening of decay path compensate for high β values. $P(\tau)$ depends on the number of emitted charged particles but it turns out to be practically insensitive to the number and nature of accompanying neutrals. Fig. 2 shows P as a function of τ for different values of the number of charged particles. We can use, with sufficient approximation, the curve for $n_{ch} = 3$, even without knowing the exact value of the branching ratio for different decay modes, as the mean charged multiplicity (according to various models) is about three.

Thus we can conclude that D mesons decaying into charged products would have been detected with an efficiency higher than $\sim 90\%$ if their mean life-time were $\tau \gtrsim 5 \times 10^{-15}$ s.

Of course the method is sensitive to any other particle produced in the interactions, charmed baryons or heavy leptons for instance, whose decay schemes are much less known.

Our sample of 28 measured events does contain at most few charmed paticles (one likely example with a longer path was already reported[4]) according to an expected production rate of about 10% of charged current neutrino events, value recently confirmed by a bubble chamber experiment[5] which observes the production of D^o mesons followed by the decay $D^o \rightarrow K^o_s \pi^+ \pi^-$. Therefore the negative result of this exploring research does not necessarily imply, at present, an upper limit for their mean life-time.

This method, when used with dimuon events or other selected "good" charm candidates, would surely give a measurement or more stringent limits on their life-times if no event were found decaying at longer distances.

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FIGURE CAPTIONS

Fig. 1 - Map of projected distances (Δ_p) of single tracks to the vertex as a function of their pulls (distance/error).
Full triangles represent tracks with anomalous measuring conditions.

Fig. 2 - Detection probability of D-mesons as a function of their mean life-time for different values of the number of charged decay products. Calculations refer to a cut on the projected distance at 0.17 μm and for $\beta = \beta^* = 1$ (β = D-meson velocity; β^* = velocity of decay products in c.m.s.).

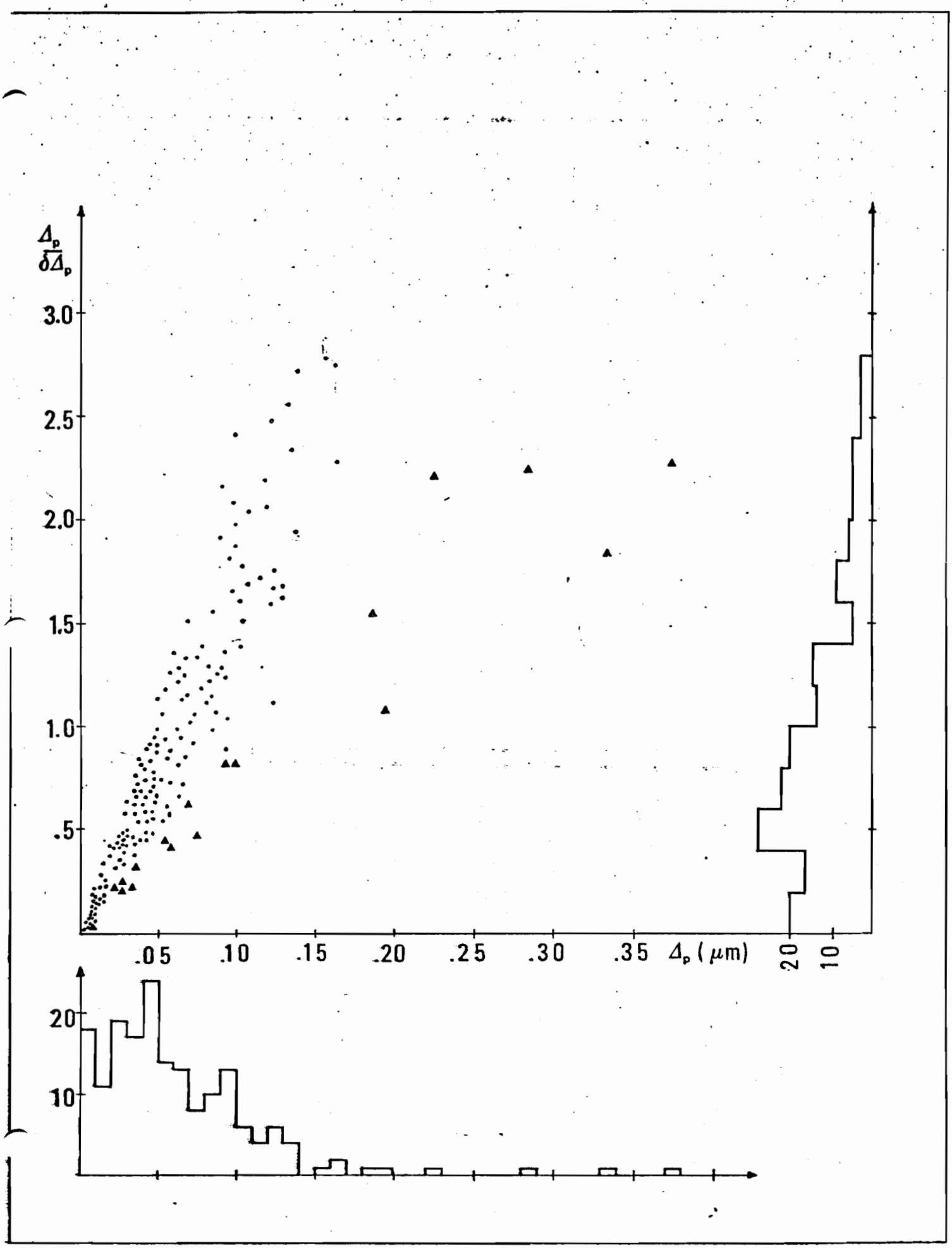
$\frac{\Delta_p}{\delta\Delta_p}$
3.0
2.5
2.0
1.5
1.0
.5
.05
.10
.15
.20
.25
.30
.35
Δ_p (μm)
20
10
20
10

FIG. 1

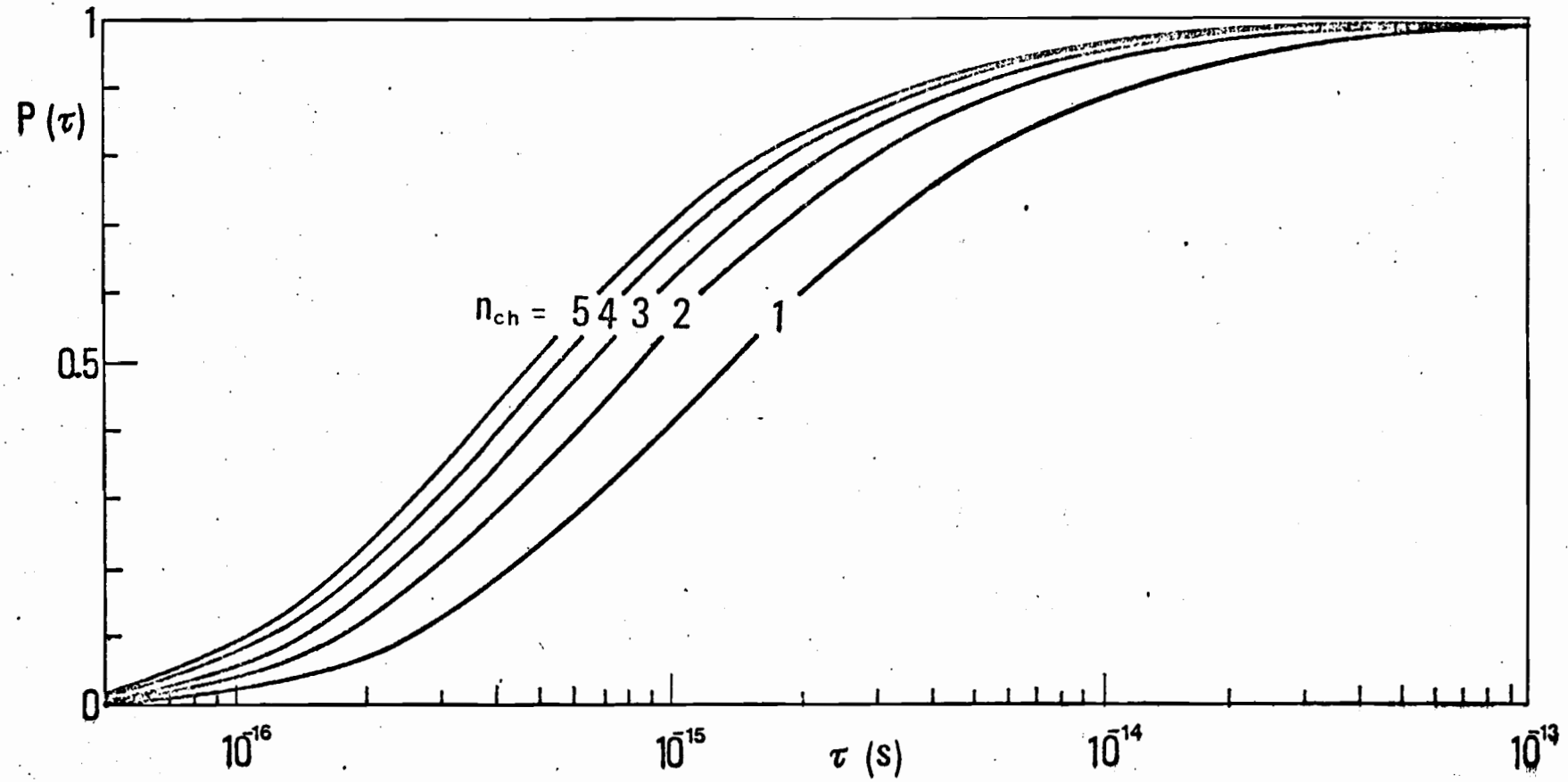

FIG. 2