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MATRIX ELEMENT OF THE $\eta'(958) \rightarrow \eta\pi^0\pi^0$ DECAY

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(Joint CERN-IHEP experiment)

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ABSTRACT

The decay $\eta' \rightarrow \eta\pi^0\pi^0 \rightarrow 6\gamma$ has been measured accurately with the GAMS-2000 spectrometer in a high statistics experiment performed at the 70 GeV IHEP accelerator. The parameters of a linear matrix element have been obtained which show that it is practically constant, with a slight dependence on only one of the Dalitz variables.

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Progress in the theory of strong interactions has shown the importance of gluon fields for the understanding of the QCD vacuum, an essential feature in the description of hadrons and the dynamics of their decay [1]. The influence of gluons (or glueballs) is particularly manifest in the case of the η' -meson, whose wave function might have a two-gluon component for 20% up to 40% of the total [2]. This could explain the abnormally high mass of η' compared to that of the other members of the pseudoscalar meson nonet. The existence of a gluon component must also influence considerably the dynamics of η' decay [3]. The influence of the gluon anomalies might be especially important in the case of the decay $\eta' \rightarrow \eta\pi\pi$ [4].

The present work is devoted to a precise measurement of the matrix element of the neutral decay

$$\eta' \rightarrow \eta \pi^0 \pi^0 \quad (1)$$

6 γ

This decay mode (BR = 8.5%) has practically not been studied in the past owing to the experimental difficulties of detecting a large number of photons simultaneously [5].

Data on the related charged decay $\eta' \rightarrow \eta\pi^+\pi^-$ have been obtained earlier, mainly in bubble chamber experiments. The global world statistics, used to determine the parameters of the matrix element of this decay [6], is 1500 events. The present work uses a data sample of neutral decays (1) which is four times larger.

This experiment has been carried out at the 70 GeV IHEP accelerator, in a 38 GeV/c secondary beam of negative particles. Quasi-monoenergetic η' -mesons are produced in the reaction:

$$\pi^- p \rightarrow \eta' n \quad (2)$$

extensively studied at Serpukhov energies [10]. Pions are focused on the liquid hydrogen target. Their interaction point is determined from the amount of Cerenkov light emitted in the hydrogen itself. A guard system of counters surrounding the target allows for the identification of the charge-exchange processes produced in $\pi^- p$ scattering which give neutral final states [5,7-9]. This includes in particular the reaction of immediate

interest. The gamma from decay (1) are detected by the hodoscope spectrometer GAMS-2000. More details about the setup and measuring procedures are given elsewhere [5,8,11,12].

The distance between target and spectrometer has been chosen to minimize the probability of the overlap of showers produced by nearby gammas incident on GAMS (for efficient use of the event-reconstruction program) while at the same time assuring a good detection over all phase space of $\eta' \rightarrow \eta\pi^+\pi^-$ [9]. During the measurements, $8.10^{11} \pi^-$ were incident on the target.

The data have been analysed following a method described previously [9,11,13]. Six γ -events, as identified by the reconstruction program, satisfying the kinematics of the reaction $\pi^-p \rightarrow \eta\pi^+\pi^-n$ at the 96% confidence level ($\chi^2 < 10$, 4C-fit, π^0, η and neutron masses fixed at their tabulated value), have been retained. In order to reduce the background, only γ with an energy higher than 0.6 GeV have been used [5]. A cut has also been applied on the distance between γ on GAMS (> 5 cm) to reduce the number of events for which the shower reconstruction program incorrectly creates a low energy γ that is in reality a statistical fluctuation in a nearby high energy shower. This selection procedure lowers the background level by a factor 3 with only a small loss (5%) of good events (1).

The effective mass spectrum of the selected $\eta\pi^+\pi^-$ systems (fig. 1) clearly displays a narrow peak, corresponding to decay (1). The position of the maximum of the peak coincides, in the limits of the experimental errors (0.3%), with the accepted tabulated value of the η' mass [14]. Its shape is in agreement with the instrumental resolution of the spectrometer GAMS-2000 ($\sigma_M/M \approx 0.6\%$). The χ^2 -distribution of the events in the peak is in good agreement with the standard χ^2 -distribution. The t -distribution of the recoiling neutron is in agreement with previous measurements of reaction (2) [10].

To construct the Dalitz plot and to determine the matrix element of decay (1), 5400 events with $938 \text{ MeV} \leq M_{\eta\pi^+\pi^-} \leq 978 \text{ MeV}$ have been used. These events have been submitted to a 5C-fit (fixing the mass of each particle, including $M_{\eta\pi^+\pi^-} = M_{\eta'}$). The resulting Dalitz plot is displayed in fig. 2 which shows that it is uniformly populated.

The mass spectra of the $\pi^0\pi^0$ and $\eta\pi^0$ pairs of these events are shown in fig. 3. They are close to pure phase space distributions. These spectra take into account the detection efficiency ϵ , which has been determined by the method of Monte Carlo using a bank of real showers [5,15]. The value of ϵ depends slightly on the mass; it changes by only 3% in the entire mass interval considered on fig. 3. The efficiency correction does not bring any visible change to the Dalitz plot (fig. 2), which remains rather uniformly populated.

The decay of the η' ($J^P = 0^-$) can be described by the phenomenological "linear matrix element" [6] :

$$M^2 = A (|1+\alpha y|^2 + cx^2) \quad (3)$$

where y and x are the Dalitz variables

$$y = (2 + m_{\eta}/m_{\pi^0}) \frac{T_{\eta}}{Q} - 1, \quad x = \frac{\sqrt{3}}{Q} (T_1 - T_2) \quad (4)$$

T_1 , T_2 and T_{η} being the kinetic energy of the two π^0 and of the η in the rest frame of the η' -meson, respectively; $Q = m_{\eta'} - m_{\eta} - 2m_{\pi^0}$ and A is a normalisation factor.

The dependence of the matrix element on each variable, x and y , after integration on the other, is shown in fig. 4. Fitting expression (3) to the data gives the following values of the parameters: $\text{Re } \alpha = -0.058 \pm 0.013$, $\text{Im } \alpha = 0.00 \pm 0.13$, $c = 0.00 \pm 0.03$. Thus, the matrix element is well described by a linear function of y with a slope

$$\alpha = -0.058 \pm 0.013 \quad (5)$$

The errors on the parameters are mostly of statistical origin. In order to estimate possible systematic errors, due to background events (fig. 1), the parameters have also been determined for two other $\eta\pi^0\pi^0$ mass bandwidths centered on the η' mass. One is narrower (948 MeV to 968 MeV) and the other is much larger (928 MeV to 988 MeV). The background differs by a factor 3 between these two bands. The resulting values of α and c differ from the values quoted above by less than 0.002. An analysis of the Dalitz plot of the events outside the η' peak gives also the same result (the matrix element (3) is constant in this case).

Because of the complex topology of the final state, a small number of $\eta \pi^0 \pi^0$ events happens to be reconstructed in a non-unique way by the reconstruction program. The six gammas may, in some cases, be combined in more than one way giving two pions and one eta. A simulation of this effect, using a bank of real showers, has shown that the number of such events is not large (1-2%) and that their Dalitz plot is nearly uniform. The corresponding systematic error on α does not exceed 0.002.

Thus, the matrix element of the decay $\eta' \rightarrow \eta \pi^0 \pi^0$ is nearly constant, depending weakly on only one of the Dalitz variables, y (4). It is well described by a linear function of y with only one parameter, the slope α . The slope determined in this experiment from the neutral decay $\eta' \rightarrow \eta \pi^0 \pi^0$ and the slope determined from the charged decay $\eta' \rightarrow \eta \pi^+ \pi^-$ (-0.08 ± 0.03) with a larger statistical error [6] are found to be in good agreement.

The slope α may be interpreted as reflecting the influence of an important gluon component in the wave function of the η' on the dynamics of its decay. Current theoretical estimates of this effect have only a preliminary character [3].

The same matrix element (3) has also been considered in a phenomenological model of the decay $\eta' \rightarrow \eta \pi \pi$ which takes into account final state interactions within the framework of scalar-meson nonet dominance [16]. The value of the slope seems to depend essentially on the still poorly known quark content of the scalar mesons [17-20].

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FIGURE CAPTIONS

Fig. 1 Invariant mass spectrum of $\eta\pi^0\pi^0$ systems produced in the reaction $\pi^-p \rightarrow \eta\pi^0\pi^0n$. The peak corresponds to the neutral decay of η' . The arrow points to the tabulated value of η' mass. The width of the fitted curve is of the order of the instrumental resolution of the spectrometer. The dashed line corresponds to the background.

Fig. 2 Dalitz plot for the η' events (two combinations per event). Mass band: 938-978 MeV.

Fig. 3 a) Invariant mass spectrum of the π^0 pairs produced in decay (1). The solid curve is the spectrum calculated with matrix element (3) with the parameters from the fit: $\alpha = -0.058$ and $c = 0$. The dashed curve represents the phase space spectrum ($M^2 = \text{constant}$). The histogram is corrected for the variation of the detection efficiency with mass. It has been normalized so that the area under the histogram is equal to the number of measured η' events.

b) The same for $\eta\pi^0$ systems. The spectrum calculated with the same parameters as above, practically coincides with the phase space distribution (solid curve).

Fig. 4 Dependence of the square of the η' neutral decay matrix element on the Dalitz variables x and y (4). The straight lines are the result of a fit of the data with expression (3) with $\alpha = -0.058$ and $c = 0$.

FIG. 1

FIG. 2

FIG. 3

FIG. 4