THE SEARCH OF TENSOR INTERACTION FOR PION AND KAON DECAYS

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Two ways to experimental studying of rare decays are described. The advantages and the disadvantages are regarded. The deviations from Standard Theory of weak interactions in some experimental results of different setups are discussed.

Introduction

This note is devoted to a possible deviation from Standard Model of weak interaction. The deviation appears from the recent experiment data on $\pi \to e\nu\gamma$ and K$\to$ $e\nu\pi^0$. In the middle of the 1980th, several experiments to study these processes were made. Main goal was to measure the ratio $\gamma = F_A/F_V$, axial-vector (F_A) and vector (F_V) weak currents [1] in a radiative pion decay. The amplitude of the radiative

$$\pi \quad \to \quad \mathbf{e}\nu\gamma \tag{1}$$

decay is traditionally described by two terms corresponding to the inner bremsstrahlung (IB) and structure-dependent (SD) radiation (Fig.1). The IB contribution is closely connected width the $\pi \to e\nu$ decay and calculated by using the standard QED methods. The SD term is parametrized by two form factors (F_V, F_A) that describe the vector (F_V) and the axial-vector (F_A) weak currents [1]. The matrix elements of decay (1) are given by:

$$M_{\rm IB} = -i\frac{eG_F V_{ud}}{\sqrt{2}} f_\pi m_e \varepsilon^\mu \overline{e}[(k/kq - p/pq)^\mu +$$

$$+\frac{\sigma_{\mu\nu}q^\nu}{2kq}](1+\gamma^5)\nu_e, \tag{2}$$

$$M_{\rm SD} = \frac{eG_F V_{ud}}{\sqrt{2}M_\pi}\varepsilon^\mu[F_v e_{\mu\nu\rho\sigma}p^\rho q^\sigma +$$

$$+iF_A(pqg_{\mu\nu} - p_\mu g_\nu)]e\gamma^\nu(1+\gamma^5)\nu_e, \tag{3}$$

where V_{ud} – CKM matrix element, $f_\pi = 131$ MeV — constant of the pion decay, ε^μ — photon polarization vector, p, k, q – 4-momenta of pion, electron, and photon; $F_{V,A}(t) = F_{V,A}(0)[1 + \Lambda_{V,A}t/{m_\pi}^2]$. The consideration of QCD interactions of ρ and a_1 mesons allows one to calculate $\Lambda_V = {m_\pi}^2/{m_\rho}^2 = 0.033$ and $\Lambda_A = {m_\pi}^2/{m_{a1}}^2 = 0.017$. It is possible to treat $F_{V,A}$ as independent of t. Accordingly to CVC, F_V is defined by π^0 life time: $|F_V| = 1/\alpha[\sqrt{2/\pi m_{\pi 0} T_{\pi 0}}] = 0.0259 \pm 0.0005$, F_A-model dependent value in the wide range from $-3F_V$ to $1.4F_V$ [2–5]. Usually, the ratio $\gamma = F_A/F_V$ is considered. The following kinematic variables are used: $x = 2E_\gamma/m_\pi$ and $y = 2E_e/m_\pi$. It is also convenient to use the variable $\lambda = (x+y-1)/x = y\sin^2(\theta_{e\gamma}/2)$. The differential probability $\pi \to e\nu\gamma$ decay is given by

$$\frac{dW_{\pi\to e\nu\gamma}}{dxdy} = \frac{\alpha W_{\pi\to e\nu}}{2\pi}[\mathrm{IB}(x,y) + \left(\frac{F_V {m_\pi}^2}{2f_\pi m_e}\right)^2 \times$$

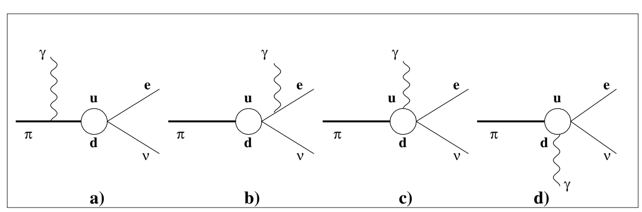

Fig.1. The contributions to the radiative decay $\pi \to e\nu\gamma$ in the framework of the quark model; a and b contain IB; c and d — SD

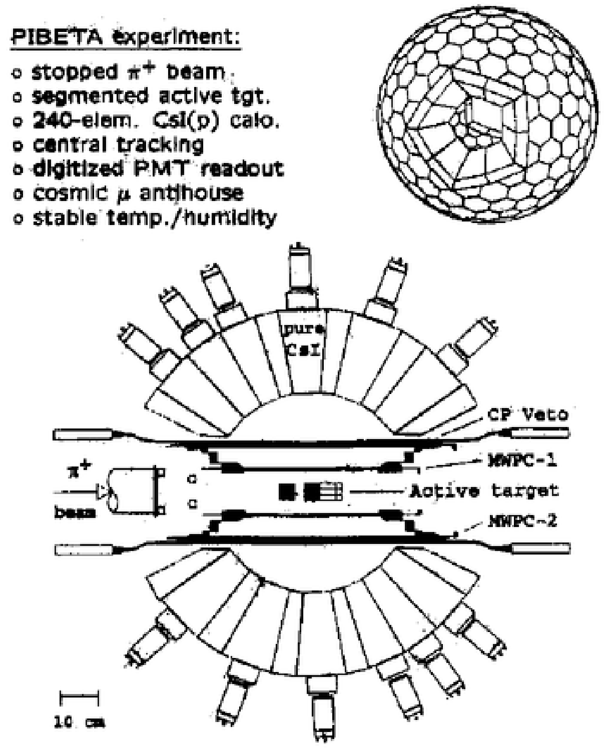

Fig.2. The layout of PIBETA setup

$$\times[(1+\gamma)^2 \mathrm{SD}^+(x,y) + (1-\gamma)^2 \mathrm{SD}^-(x,y)]], \quad (4)$$

where IB and $\mathrm{SD}^{\pm}$ are the known functions:

$$\mathrm{IB}(x,y) = \frac{(1-y)[(1-x)^2+1]}{x(x+y-1)},$$
$$\mathrm{SD}^+(x,y) = (1-x)^2(x+y-1),$$
$$\mathrm{SD}^-(x,y) = (1-x)^2(1-y). \quad (5)$$

Two experimental methods of the decay measuring: one used decays of stopped pions and other – decay in flight. Typical layouts are shown in two figures: in Fig.2 the layout PIBETA for stopped pions and, in Fig.3, the ISTRA setup for pion decays in flight.

All the previous experimental studies of decay (1) were made with stopped pions. Such measurements are sensitive to the SD^+ contribution mainly and, thus, yield two different values for γ [6,7]. The high statistics measurements at SIN (now PSI) give the values [8] $\gamma = 0.52 \pm 0.06$ and $\gamma = -2.48 \pm 0.06$, the positive value being more likely than the negative one. The positive sign of γ was confirmed by the LAMPF experiment [9], where the unique (3.5 standard deviations) value $\gamma = 0.25 \pm 0.12$ was found. These results have been confirmed additionally by the study of the $\pi^+ \to e^+ \nu e^+ e^-$ decay [10]. Nevertheless, the experimental study of the $\pi \to e\nu\gamma$ decay could not have been considered as completed since (i) there was a discrepancy (approximately 2 st. dev.) between the values obtained at SIN and at LAMPF, (ii) the selection of the sign of γ in the $\pi \to e\nu\gamma$ experiments was not sufficiently reliable, and (iii) the studied kinematical region was relatively small (Fig.4).

The experimental results of studying the $\pi \to e\nu\gamma$ decay are summarized in Table 1. (W – the ratio of the probabilities of positive and negative values of γ.)

The high energy of the decaying particles allows to overcome the principal difficulties encountering in experiments with stopped pions. Owing to the high detection efficiency, the wide range of measured angles and energies of secondary particles, and the substantial suppression of the background from the

$$\begin{array}{lcl} \pi \to \mu\nu & \text{and} & \pi \to \mu\nu\gamma \\ \quad \longrightarrow e\nu\nu\gamma & & \quad \longrightarrow e\nu\nu \end{array}$$

decays, it is possible to distinguish decay (1) in a wide range of kinematic variables with only a small admixture of the background. INR experiment was performed at the ISTRA set up at the end of the 1980th with 17 GeV pion beam produced by the IHEP U-70 accelerator. The admixture of kaons and muons in the beam was, respectively, 3 and 2%. Special attention was paid to the purity of the pion isolation. Pions decayed in the 10-m long decay volume. Pion and electron tracks were, respectively, measured by the scintillation hodoscopes [11] and by the proportional chambers with an induced charge readout [12]. The electrons and photons from the decays were detected in the 20x24 array of a lead glass EM calorimeter [13]. The experimental setup is described in detail in our previous papers on the kaon decays [14] and in the complete review of the ISTRA detector [15]. Main results of the study of radiative pion decay were published in [16]. About $3.7 \cdot 10^{11}$ pions passed through the setup, yielding $14.5 \cdot 10^6$ triggers. The main requirements for recording events on the tape were (i) a single charged particle (an electron) coming out of the decay volume must be observed, and (ii) the energy absorption in the EM calorimeter be more than 1 GeV. We get: $\gamma = F_A/F_V = 0.41 \pm 0.23$. The value $\gamma = -2.4$ is suppressed by a factor $W = 5 \cdot 10^9$, which corresponds to 6.7 standard deviations.

The wide range of the kinematic variables in the INR experiment has enabled us to determine the value of F_V without using the CVC hypothesis. Considering the value of F_V to be a free parameter in the fit, one gets $|F_V| = 0.014 \pm 0.009$. The obtained result agrees both with the CVC prediction and with the SINDRUM value

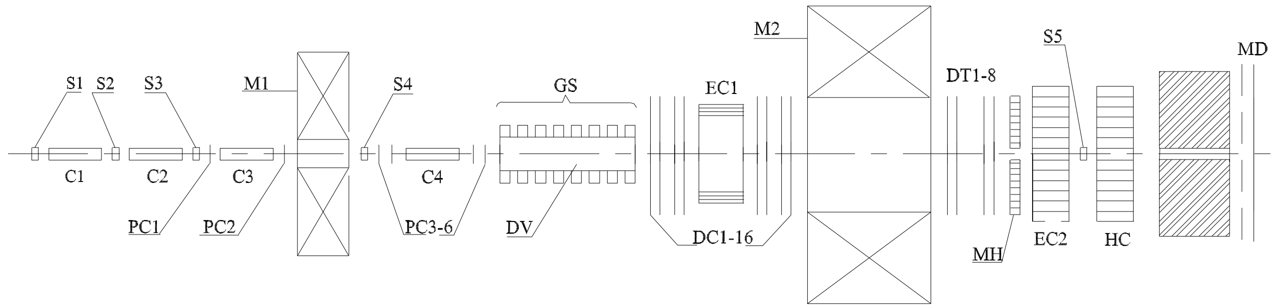

Fig.3. The layout of ISTRA setup

$|F_V| = 0.023 \pm 0.015$ [10]. The authors of [16] also performed the data processing in a more general way. One can present the decay rate density as

$$N_{\pi \to e\nu\gamma}(x, y) = a_{\mathrm{IB}} N_{\mathrm{IB}}(x, y) +$$

$$+a_{\mathrm{SD}^+} N_{\mathrm{SD}^+}(x, y) + a_{\mathrm{SD}^-} N_{\mathrm{SD}^-}(x, y), \qquad (6)$$

where $a_{\mathrm{IB}}, a_{\mathrm{SD}}$ are free parameters proportional to the probabilities of the corresponding processes. By substituting distribution (5) into the likelihood function, one can determine the values of these probabilities. The recalculated results for the branching ratios for the kinematic region $x > 0.3$, $y > 1 - 0.8x$, in which decay (1) was effectively detected, are presented in Table 2.

The results of the fit with the constraint $a_{\mathrm{SD}^-} > 0$ are shown in the parenthesis. For comparison, the authors give the expected values: the QED calculation for IB radiation and the SD contributions evaluated by using the results of experiments with stopped pions [1].

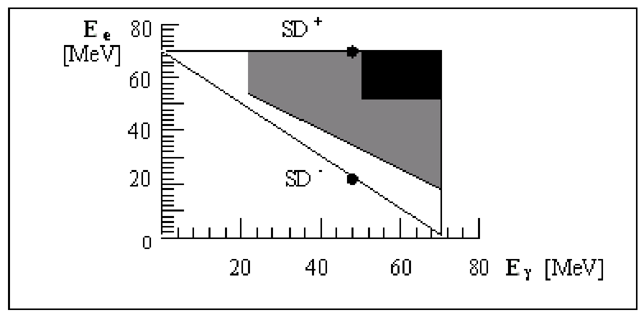

Fig.4. The kinematic regions of the $\pi \to e\nu\gamma$ decay at the ISTRA setup (gray)and in the stopped pion experiments (black). Black points correspond to the maximum values of the $SD^{\pm}$ terms

There is a good agreement for the IB and SD^+ contributions. The discrepancy for the total branching ratio (more than 3 standard deviations) is due to the negative (unphysical) value of the SD contribution. The authors cannot explain this result by a systematic error due to the specific features of event detection and/or their processing. So, the authors of [16] found some

T a b l e 1

Experiment	$\gamma = F_A/F_V$	W	F_V	Br.ratio (10^7)
CERN [6] (63)	$+0.26 \quad -1.98$	–	–	0.3 ($E_e, E_\gamma > 48$ MeV)
LBL [7] (78)	$+0.48 \pm 0.12$ -2.42 ± 0.12	0.7	–	0.56 ± 0.07 $E_e > 56$ MeV, $\Theta_{e\gamma} > 132^o$
SIN [8] (86)	$+0.52 \pm 0.06$ -2.48 ± 0.06	8.5	–	–
LAMPF [9] (86)	$+0.25 \pm 0.12$	2175	–	–
SINDRAM [17] (84)	$+0,75 \pm 0.31$	$4 \cdot 10^7$	$0.023^{+0.015}_{-0.013}$	–
ISTRA [16] (90)	$+0.41 \pm 0.23$	$4 \cdot 10^9$	$+0.014 \pm 0.009$	$+1.61 \pm 0.23$ ($E_\gamma > 21$ MeV $E_e > 70$ MeV $- 0.8 E_\gamma$) Br(IB) $= 1.62 \pm 0.20$ Br(SD^+) $= 0.56 \pm 0.21$ Br(SD^+) < 0.3(95%CL)

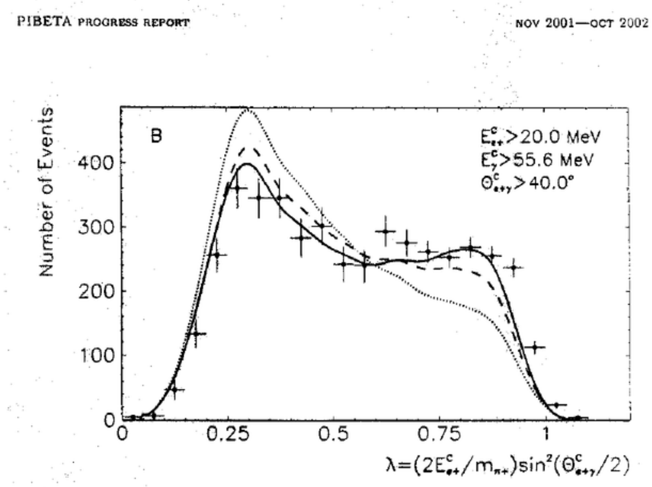

Fig.5. Tin kaon decays

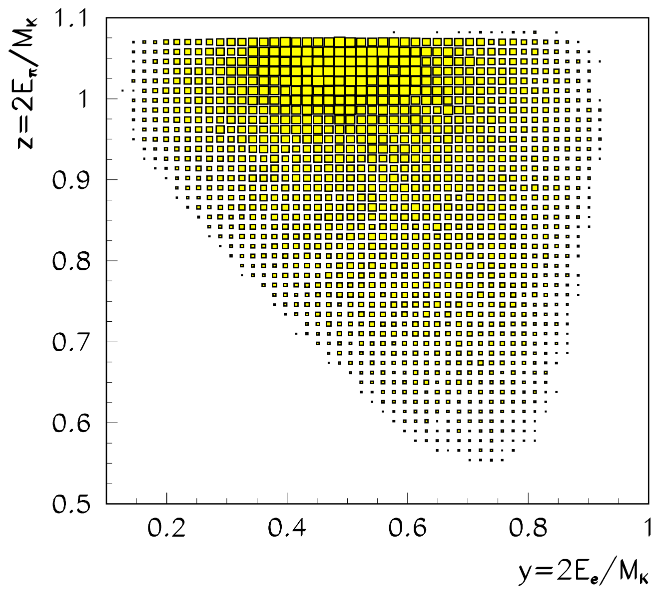

Fig.6. Dalitz plot ($y = 2E_e / M_K$; $Z = 2E_\pi / M_K$) for the selected $K^- \to e^-\nu\pi^0$ events after the 2C fit

discrepancy for the total decay probability, and the kinematic distributions for missing events similar to that of SD^- radiation [16]. It should be mentioned [17] that decay (1) may be sensitive to the search for deviations from the Standard Model since a $\pi \to e\nu\gamma$ decay is strongly suppressed. In particular, the negative value for a_{SD} may be simulated by adding the tensor radiation term to the structure dependent amplitude:

$$M_T = i(eG_F V_{ud}/\sqrt{2})\varepsilon^\mu q^\nu F_T u(p_e)\sigma_{\mu\nu}(1+\gamma^5)\nu(p_\nu). \quad (7)$$

The decay rate densities for the SD^- radiation and the interference term between the inner bremsstrahlung and the tensor radiation are similar, so the destructive interference may reproduce the results of the fit, giving $F_T = (-5.6 \pm 1.7)\cdot 10^{-3}$. This value does not contradict the listed constraints on a tensor coupling from nuclear beta decay as well as from muon decay (if universality is supposed) [17]. This result also does not contradict the previous experiments carried out with stopped pions either [18].

Several works [19] were devoted to the study of a possible deviation from SM in radiative pion decay. In one of them, the involving of antisymmetric tensor fields into the standard electroweak theory allows one to explain results of this work as well as [20]. It is evident that additional experimental and theoretical investigation of this problem should be carried out.

Recently a report on preliminary results performed by the PIBETA Collaboration from PSI meson factory has appeared [21]. The fits were made in two-dimensional kinematic space of $x = 2E_\gamma/m_\pi$ and $\lambda = (x+y-1)/x = y\sin^2(\Theta_{e\gamma}/2)$ on a very large statistical material (60k events $\pi \to e\nu\gamma$ decays). Fitting the experimental data requires $F_T \neq 0 (F_T \cong 0.0017 \pm 0.0001)$. Here is the quotation from PIBETA Annual Progress Report: " Thus, like the ISTRA data, our data appear to call for a destructive interference between the IB term and a small negative tensor amplitude."

The results from ISTRA and PIBETA setups don't solve the problem. That is, the study should be continued.

The Lorentz invariant form of the matrix element for the decay $K^- \to l^-\nu\pi^0$ is [23]:

$$M = \frac{G_F \sin\theta_C}{\sqrt{2}}\bar{u}(p_\nu)(1+\gamma^5)[m_K f_S -$$
$$-\frac{1}{2}[(P_K + P_\pi)_\alpha f_+ + (P_K - P_\pi)_\alpha f_-]\gamma^\alpha +$$
$$+i\frac{f_T}{m_K}\sigma_{\alpha\beta}P_K^\alpha P_\pi^\beta]v(p_l). \quad (8)$$

It consists of scalar, vector and tensor terms, $f_S, f_T, f_\pm$ are the functions of $t = (P_K - P_\pi)^2$.

Assuming a linear dependence of $f_+ = f_+(0)(1 + \lambda_+ t/{m_\pi}^2)$ and real constants f_S, f_T, we constructed the Dalitz plot. From the experimental Dalitz plot (Fig. 6), the parameters λ_+, f_S, f_T are extracted after the subtraction of the normalized MC estimated background. The result of the fit are summarized in Table 3.

The comparison of these results with the most recent $K^\pm$ data [20,24,25] shows that our statistics, at

T a b l e 2. The probabilities of $\pi \to e\nu\gamma$ decay in the kinematic region $E > 21$ MeV, $E_e > 70 - 0.8E$. The results of the fit with constraint $a_{SD} > 0$ are shown in parentheses

Process	Probability ($\times 10^7$)	Expected calcul. value ($\times 10^7$)	Ways to obtain expected results
IB	1.62 ± 0.20 (1.30 ± 0.17)	1.70	QCD calcul.
SD^+	0.56 ± 0.21 (1.40 ± 0.20)	0.67 ± 0.07	experimental data [7] [8] [9]
SD^-	-0.58 ± 0.20 (< 0.3, 95%CL)	0.04	experimental data for SD^+, CVC, $\gamma > 0$
total	1.61 ± 0.23 (1.70 ± 0.22)	2.41 ± 0.007	

T a b l e 3. $K^- \to e^-\nu\pi^0$

ISTRA$^+$ (133k) [28]				
$\lambda_+ = 0.0306 \pm 0.0018$; $f_T / f_+ = -0.0444 \pm 0.068$; $f_S / f_+ = -0.0151 \pm 0.025$				
λ_+	0.0278 ± 0.0026	Shimizu	(00)	41k [24]
	0.0284 ± 0.0027	Akimenko	(91)	32k [20]
	0.0290 ± 0.0040	Bolotov	(88)	62k [27]
F_S	$0.002 \pm 0.026 \pm 0.014$	Shimizu	(00)	41k [24]
	$0.07 \pm 0.016 \pm 0.016$	Akimenko	(91)	32k [20]
F_T	$-0.01 \pm 0.14 \pm 0.09$	Shimizu	(00)	41k [24]
	$0.53 \pm 0.010 \pm 0.1$	Akimenko	(91)	32k [20]

present, is the highest in the world and the errors are smaller than in [20,24] and comparable with [25]. These results do not confirm the observation of a significant f_S and f_T in [20]. They are in a good agreement with [24,25,27] and with the theoretical calculation for $\lambda_+ = 0.031$ [26].

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ПОШУКИ ТЕНЗОРНОЇ ВЗАЄМОДІЇ В РОЗПАДАХ ПІОНІВ ТА КАОНІВ

В. Болотов, В. Дак

Р е з ю м е

Описано два способи експериментального вивчення рідкісних розпадів. Розглянуто їх переваги та недоліки. Обговорюються відхилення від стандартної теорії слабкої взаємодії в деяких експериментальних результатах, отриманих на різних установках.

ПОИСКИ ТЕНЗОРНОГО ВЗАИМОДЕЙСТВИЯ В РАСПАДАХ ПИОНОВ И КАОНОВ

В. Болотов, В. Дак

Р е з ю м е

Описаны два способа экспериментального изучения редких распадов. Рассмотрены их преимущества и недостатки. Обсуждаются отклонения от стандартной теории слабых взаимодействий в некоторых экспериментальных результатах, полученных на различных установках.