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ON MEASURING THE STRUCTURE EMISSION FORM FACTORS OF THE $K^+ \to \mu^+ \nu \gamma$ DECAY IN THE FERMILAB EXPERIMENT E761

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The possibility to measure contributions of the structure and interference terms of the amplitude of emission for a photon with negative helicity in the $K^+ \to \mu^+ \nu \gamma$ decay using data of the Fermilab E761 hyperon experiment is considered.

Fig. - 7, ref. - 14

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1. INTRODUCTION

The radiative decay $K^+ \to l^+\nu\gamma$ ($l^+ = e^+, \mu^+$) provides interesting information on the properties of hadronic weak currents. Since the final state strong interactions are absent, it is possible to probe the kaon electroweak structure in the most pure way.

The following processes contribute to this decay: the internal bremsstrahlung (IB), the structure radiation (SD) when the photon is emitted from intermediate states governed by strong interactions, and the interference term between them (INT). The structure decay amplitude (SD) can be written in terms of vector (F_V) and axial (F_A) form factors which are considered in a number of papers (see Tab.1). The SD component consists of two terms SD_+ and SD_- which are proportional to $[F_V+F_A]^2$ and $[F_V-F_A]^2$. These terms correspond to emission of photons with positive and negative helicities, respectively. The interference component (INT) also consists of two parts which are proportional to $[F_V+F_A]$ (the INT_+ term) and $[F_V-F_A]$ (the INT_- term). So the branching ratio of $K^+ \to \mu^+\nu\gamma$ decay can be written as [8]:

$$W(K^+ \to \mu^+\nu\gamma) = W_{IB} + 4.9\cdot 10^{-4} M_K((F_V+F_A)^2 + (F_V-F_A)^2) - 10^{-4}(F_V+F_A)M_K + 7.2\cdot 10^{-4}(F_V-F_A)M_K \qquad (1)$$

where W_{IB} depends on a photon energy cut. For instance $W_{IB}(E_\gamma > 10$ MeV in the centre of mass system (c.m.s.) of kaon$) = 4.3\cdot 10^{-3}$. It should be noted that the measurement of the INT term is very important for determination of the form factors since one can

determine a sign of the decay amplitude as well as its magnitude. However, in the case of the $K_{e\nu\gamma}$ decay mode it is practically impossible to determine the sign of the form factors because the INT and IB terms are negligibly small compared with the structure emission [8]:

$$W(K^+\to e^+\nu\gamma) = W_{IB} + 6.5\cdot10^{-4}M_K((F_V+F_A)^2 + (F_V-F_A)^2) - $$
$$- 4.6\cdot10^{-8}(F_V+F_A)M_K + 8.03\cdot10^{-8}(F_V-F_A)M_K; \qquad (2)$$

$W_{IB}(E_\gamma>10$ MeV in c.m.s. of the kaon$)=1.17\cdot10^{-7}$.

The possibility of measuring the INT term is a unique feature of the $K^+\to\mu^+\nu\gamma$ mode.

Only few experiments have been done so far. For the $K_{e\nu\gamma}$ mode two experiments were performed at the CERN PS and the values of the form factors were obtained [10]:

$$|F_V+F_A|_{(e)}M_K = 0.153 \pm 0.011, \qquad (3a)$$

$$|F_V-F_A|_{(e)}M_K < 0.5 . \qquad (3b)$$

For the $K_{\mu\nu\gamma}$ mode form factors have been measured at the KEK [11]

$$|F_V+F_A|_{(\mu)}M_K < 0.23, \qquad (4a)$$

$$-2.5 < (F_V-F_A)_{(\mu)}M_K < 0.3 \qquad (4b)$$

and ITEP experiments [12]

$$-1.2 < (F_V+F_A)_{(\mu)}M_K < 1.1 , \qquad (5a)$$

$$-2.2 < (F_V-F_A)_{(\mu)}M_K < 0.6 . \qquad (5b)$$

Although the $K_{e\nu\gamma}$ experiment [10] has given a strong constraint on the magnitude of F_V+F_A (3a), an uncertainty of F_V-F_A is still large and one could not independently determine the values of the vector and axial form factors.

The result (3a) agrees within two standart deviations with a prediction of the chiral theory [9]: $|F_V+F_A|M_K=0.134$. For the value of F_V-F_A the theory gives $|F_V-F_A|M_K=0.049$. This value is by one order of a magnitude smaller than the present

experimental limit (2-4). As we will show the experimental data obtained during the 1990 exposure of the E761 apparatus in the Fermilab hyperon beam [13] can be used for measurements of SD_ and INT_ terms in the $K^+ \to \mu^+ \nu \gamma$ decay.

2. AN ESTIMATION OF THE KAON FLUX.

A simplified E761 experimental set up [13] (the Fig.1) has been used to estimate a geometrical efficiency for decays of beam particles (Σ^+ and K^+). Parameters of the setup are presented in Table 2.

On the first step we have simulated the missing neutral mass squared* M_X^2 distributions for the decays $\Sigma^+ \to p + X$ ($X = \gamma, \pi^0$). These distributions are shown on the Fig.2 and are found to be in a reasonable agreement with experimental ones E761 [13]. Then we have simulated the M_X^2 distributions for $K^+ \to \pi^+ \pi^0$, $K^+ \to \mu^+ \pi^0 \nu$ and $K^+ \to e^+ \pi^0 \nu$ decays ($X = \pi^0$, $\pi^0 \nu$) assuming $M_K = M_\Sigma$ and the masses of π^+, μ^+ and e^+ are equal to M_p. These distributions are also shown on the Fig.2. We have compared the distribution for a sum of all processes with the experimental data [13] and estimated of the ratio of K^+ and Σ^+ fluxes as follows: $N_K/N_\Sigma \cong 10.5$. Note, that in the Fig.2 we give numbers of observed events in the region $-0.03 < M_X^2 < 0.06$ GeV^2/c^4. For further analysis we have considered the above decays over the total M_X^2 range together with the $K^+ \to \mu^+ \nu \gamma$ decay. These distributions are shown in the Fig.3.

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* $M_X^2 = (P_2 - P_1)^2$; where P_1 is a four-momentum of the incoming particle, and P_2 is a four-momentum of the charged particle from the decay.

3. BACKGROUND REJECTION.

To select the $K^+ \to \mu^+ \nu \gamma$ events we have made the following cuts.

At first we note that the $\Sigma^+ \to p\pi^0$ and $\Sigma^+ \to p\gamma$ decays are found to be falling into the region [-0.03,0.06] GeV^2/c^4 (see Fig.3). Excluding this region we discard backgrounds from the Σ^+ decays and only a small fraction of the $K^+_{\mu\nu\gamma}$ events.

Secondly we consider the kaon decays with a π^0. The Table 3 lists calculated fractions of $K^+ \to \pi^+\pi^0$, $K^+ \to \mu^+\pi^0\nu$ and $K^+ \to e^+\pi^0\nu$ events with different combinations for γ detection, using the geometry of the E761 photon detector (PD) shown in the Fig.1 [13]. These decays can be treated as a background when one of the π^0 decay photons hits the region (b) and another escapes detection in the region (c). Such combination takes place only for primary kaons with an angle θ between its momentum p_K and the beam axis more than $1.1 \cdot 10^{-3}$ rad as it is shown in the Fig.4a. The fraction of all events with $\theta < 1.1 \cdot 10^{-3}$ rad is estimated as β=0.729 (Fig 4b) and we use this cut to eliminate background from $K^+ \to \pi^+\pi^0$, $K^+ \to \mu^+\pi^0\nu$ and $K^+ \to e^+\pi^0\nu$ decays. After applying the above cuts we consider possible backgrounds as negligible and further analyse only $K^+ \to \mu^+\nu\gamma$ decays.

4. $K^+ \to \mu^+\nu\gamma$ DECAY ANALYSIS.

To estimate the number of $K_{\mu\nu\gamma}$ events (N_i) from each (i) term (i=1,...,5) we use the following formulae:

$$\frac{N_i}{N(\Sigma^+\to p\gamma)} = \frac{N_K}{N_\Sigma}\cdot\frac{\varepsilon_d^K}{\varepsilon_d^\Sigma}\cdot\frac{\varepsilon_g^i\,\varepsilon_{cut}^i}{\varepsilon_g^\Sigma}\cdot\frac{Br(K^+_{\mu\nu\gamma},\ i\ \text{term})}{Br(\Sigma^+\to p\gamma)} \qquad (6)$$

where

$N(\Sigma^+\to p\gamma)=67K$ - the estimated number of observed of $\Sigma^+\to p\gamma$ decay events [13];

$Br(\Sigma^+\to p\gamma)=1.25\cdot10^{-3}$ - the branching ratio of the $\Sigma^+\to p\gamma$ decay [14];

$N_K/N_\Sigma = 10.5$ as estimated above in part 2;

$\varepsilon_d^K= 5\cdot10^{-3}$ and $\varepsilon_d^\Sigma = 0.844$ - the fractions of K^+ and Σ^+ decaying in the decay region;

$\varepsilon_g^\Sigma = 0.6$ - a geometry efficiency for the $\Sigma^+\to p\gamma$ decay;

ε_g^i - a geometry efficiency for the i-term of the $K_{\mu\nu\gamma}$ decay (Table 4);

ε_{cut}^i - a survival ratio for the i-term of the $K_{\mu\nu\gamma}$ decay after the cuts (Table 4).

The branching ratios of the SD_+ and INT_+ terms in the $K_{\mu\nu\gamma}$ mode have been calculated using the formula (1) and the experimental value of $|F_V+F_A|M_K=0.153$ (3a). For the branching ratios of the SD_- and INT_- terms we have used the value predicted by the chiral theory [9]: $|F_V-F_A|M_K=0.049$.

A structure emission from the $K^+_{e\nu\gamma}$ is also expected to be seen in the experiment. There is no need to separate the $K^+_{\mu\nu\gamma}$ and $K^+_{e\nu\gamma}$ SD contributions in the experiment since the same form factors describe the structure emission in these modes.

Taking a known value of the branching ratio of the $K^+_{e\nu\gamma}(SD_+)$ term [14], the theoretical prediction for

$|F_V-F_A|M_K=0.049$ [9] and the efficiencies after the cuts above, we expect to observe 8.8 events from the SD_+ term and 1.1 events from the SD_- term (Table 5).

The main problem remained is to suppress the $K^+_{\mu\nu\gamma}$(IB) component. We use the fact that in the kaon c.m.s. the behaviour of the IB term strongly differs from that for other terms. In the Fig.5a-e two dimensional plots of a muon momentum P_μ versus a photon momentum P_γ in the kaon c.m.s. are presented. We found the region on the p_μ-p_γ plot (Fig 6) where the value F_V-F_A (the sum of SD_- and INT_- contributions) will be measured with minimal error. For this region an estimated number of events due to these two contributions is:

$$769((F_V-F_A)M_K)^2+544(F_V-F_A)M_K=29\pm\sqrt{349} \qquad (7)$$

There are two solutions for the value of $(F_V-F_A)M_K$ as shown in Fig.7 together with the results of others experiments. The first solution $-0.8 < (F_V-F_A)M_K < -0.7$ is excluded by the CERN data [10] and finally we will have:

$$\underline{0 < (F_V-F_A)M_K < 0.1 \text{ on } 90\% \text{ c.l.}}$$

These limits are several times lower than the present ones (3-5).

5. CONCLUSION

The possibility of measuring the $K^+\to\mu^+\nu\gamma$ decay is considered in the hyperon beam E761 experiment. It is shown that the structure emission form factors can be measured with several times better accuracy than in the previous experiments.

Discussion with P.Cooper and J.Lach are gratefully asknowleged.

Table 1. Theoretical predictions for the form factors in the $K \to l\nu\gamma$. *

Models	Predictions	Comments
K^*, K_A – dominance; dispersion relations. [1-3]	$\lvert F_V(0)\rvert M_K = 0.12$	an uncertainty of 20% arises from variety of SU(3) violation schemes
	$\lvert\gamma\rvert = \begin{cases} 0.05 \\ 0.11 \end{cases}$ [1]	M_{K_A} = 1260 MeV M_{K_A} = 1330 MeV
	$\lvert\gamma\rvert = \begin{cases} 0.48 \\ 0.58 \end{cases}$ [2]	variety of SU(3) violation schemes
	$\lvert\gamma\rvert = \begin{cases} 0.38 \\ 0.44 \end{cases}$ [2]	a soft-kaon approximation
	$\lvert\gamma\rvert = 0.14$ [3]	a hard-kaon approximation
the electroweak axial-vector anomaly [4]	$F_V M_K = 0.084$ $F_A M_K = 0.046$	current algebra, PCAC
the virton – quark model [6]	$\gamma = 0,21$	taking into account K–$Q_1(1280)$ exchange
the chiral theory [9]	$\lvert F_V + F_A\rvert M_K = 0.134$ $\lvert F_V - F_A\rvert M_K = 0.049$	

* table 1 $\gamma = F_A/F_V$

Table 2. Parameters of the E761 set up.

1. a length of the decay region	1402.75 cm
2. a length from the start of the decay region to the PD	3284.79 cm
3. a size of the PD with the hole	90x90 cm^2 7.5x7.5 cm^2
4. Σ^+, K^+ beam momentum	375 ± 20 GeV/c
5. Σ^+, K^+ beam mean angle spread	10^{-3} rad
6. a momentum measurement error of the primary Σ^+, K^+ beam	0.7% (σ)
7. a momentum measurement error for the secondary charged particle	0.2% (σ)
8. an angular resolution for the hyperon beam particle	12 μrad horiz. 5 μrad vertic.
9. an angle resolution for the secondary charged particle	9 μrad horiz. 6 μrad vertic.
10. the trigger is a charged particle in the hole (the region a) and one or more γ's in the PD (the region b)	$E_\gamma \geq$ 5 GeV
11. $N(\Sigma^+ \to p\gamma)$ $N(\Sigma^+ \to p\pi^0)$	$6.7 \cdot 10^4$ $4.8 \cdot 10^7$

Table 3. Fractions of the K^+-decays with different combinations of γ's detected in the photon detector.

—	γ_1 in (b) γ_2 in (a)	γ_1 in (b) γ_2 in (b)	γ_1 in (b) γ_2 in (c)
$K^+ \to \pi^+\pi^0$	0.894	0.105	$9.9\cdot10^{-4}$
$K^+ \to \mu^+\pi^0\nu$	0.902	0.097	$8.9\cdot10^{-4}$
$K^+ \to e^+\pi^0\nu$	0.891	0.108	$1.03\cdot10^{-3}$

Table 4. Contributions of the various terms of the $K^+ \to \mu^+\nu\gamma$ decay.

i	Term	ε_g	ε_{cut}	Branching ratio	N_{events}
1	IB	0.210	0.486	$4.3\cdot10^{-3}$ $E_\gamma>10$ MeV	2451
2	SD_+	0.354	0.343	$1.15\cdot10^{-5}$	7.8
3	SD_-	0.323	0.633	$0.12\cdot10^{-5}$	1.4
4	INT_+	0.295	0.491	$1.53\cdot10^{-5}$	12.4
5	INT_-	0.308	0.615	$3.53\cdot10^{-5}$	37.4

Table 5. Contributions of the SD_+ and SD_- terms in the $K^+ \to e^+\nu\gamma$ decay.

i	Term	ε_g	ε_{cut}	Branching ratio	N_{events}
2	SD_+	0.323	0.32	$1.53\cdot10^{-5}$	8.8
3	SD_-	0.207	0.63	$0.16\cdot10^{-5}$	1.1

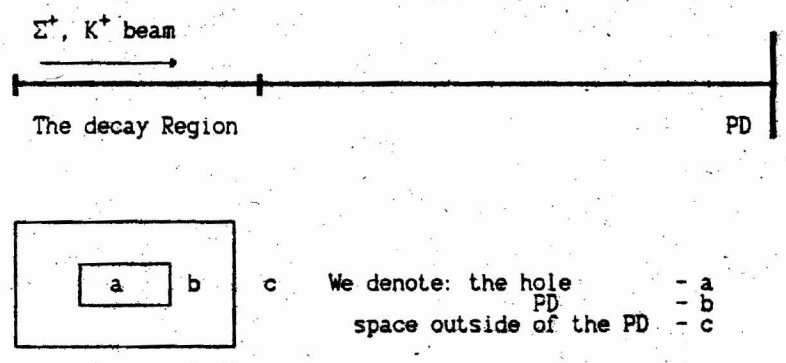


Fig. 1. A simplified E761 experiment set up and a transverse projection of the photon detector (PD).

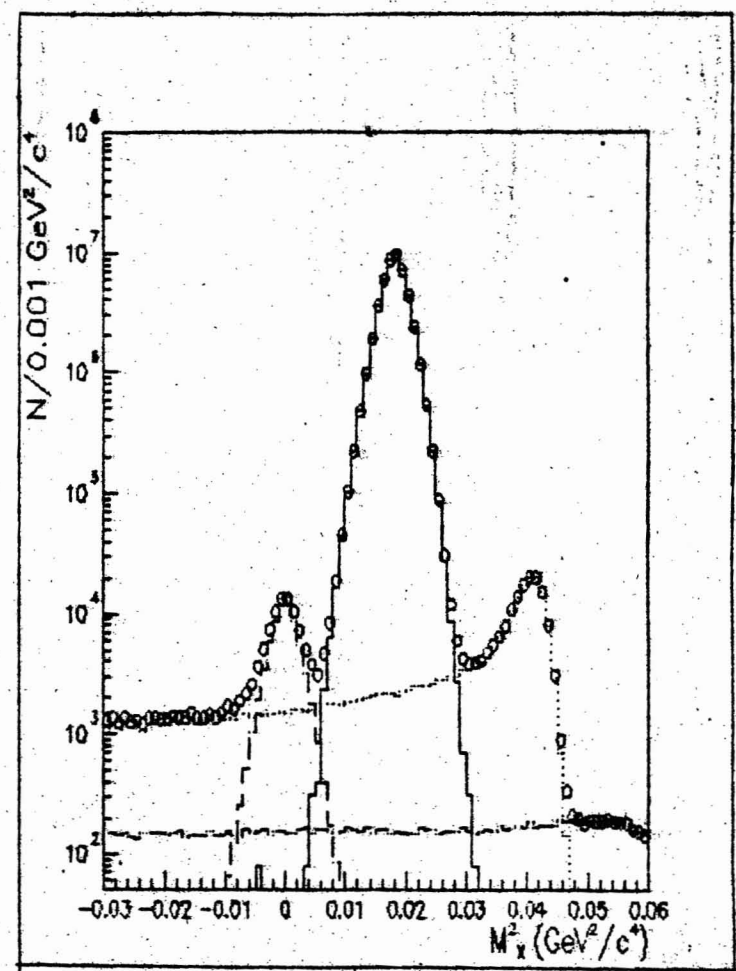


Fig. 2. Simulated distributions of the missing mass squared of the neutral particles M_x^2 in the range of -0.03 - 0.06 GeV^2/c^4. The full line - $\Sigma^+ \to p\pi^0$ (48 M ev.); the dashed line - $\Sigma^+ \to p\gamma$ (67 K ev.); the dotted line - $K^+ \to \pi^+\pi^0$ (250 K ev.); the dash-dotted line - a sum of $K^+ \to e^+\pi^0\nu$ and $K^+ \to \mu^+\pi^0\nu$ (19 K ev.); the open circles - a sum of all contributions

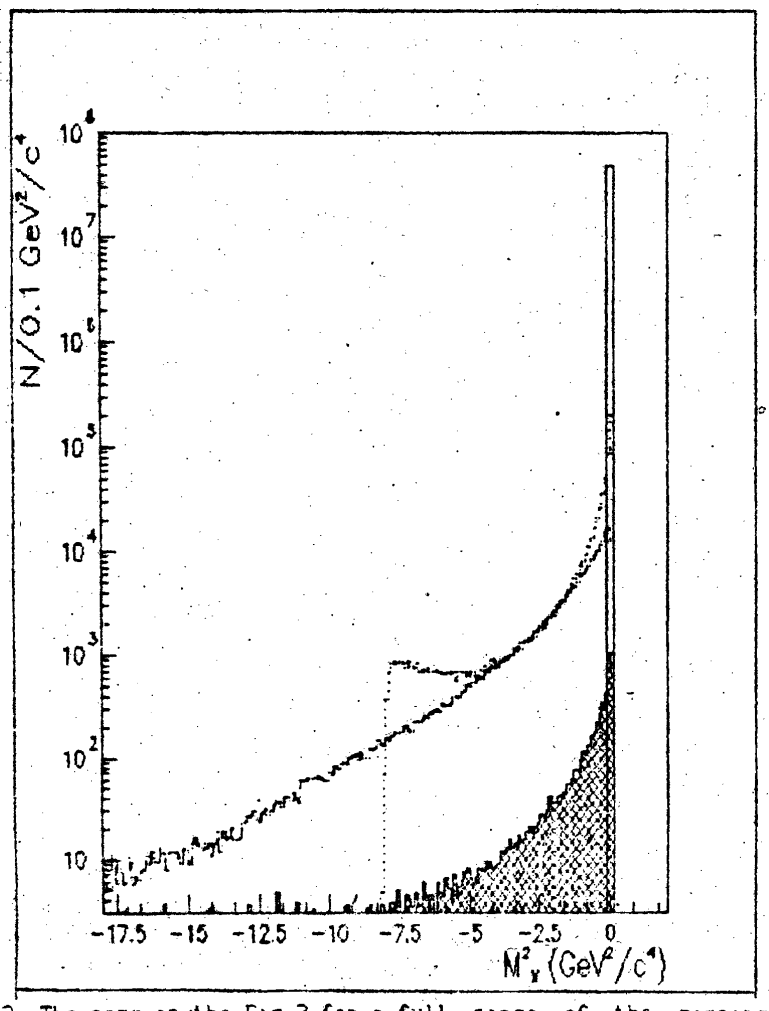


Fig 3. The same as the Fig 2 for a full range of the missing neutral mass squared M^2_γ.*. The blackened histogramm markes a distribution for the $K^+ \to \mu^+ \nu \gamma$ decay (5.1 K ev.).

* Expected number of events are: $K^+ \to \pi^+ \pi^0$ - 588 K ev.; $K^+ \to e^+ \pi^0 \nu$ and $K^+ \to \mu^+ \pi^0 \nu$ - 200 K ev.

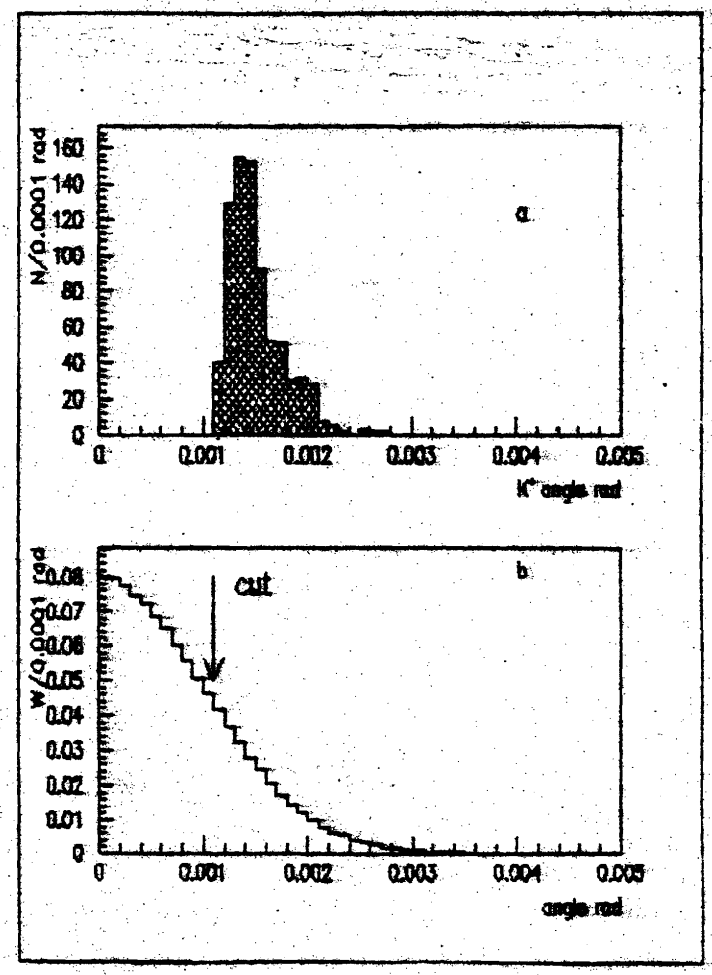


Fig. 4. Beam angle distributions for the incoming particles:

a – kaons decaying into π^0's giving only one gamma in the photon detector; contribution of the different kaon decays are as follows: $K^+ \to \pi^+\pi^0$ - 589 ev.; $K^+ \to e^+\pi^0\nu$ and $K^+ \to \mu^+\pi^0\nu$ - 195 ev.

b – all beam particles.

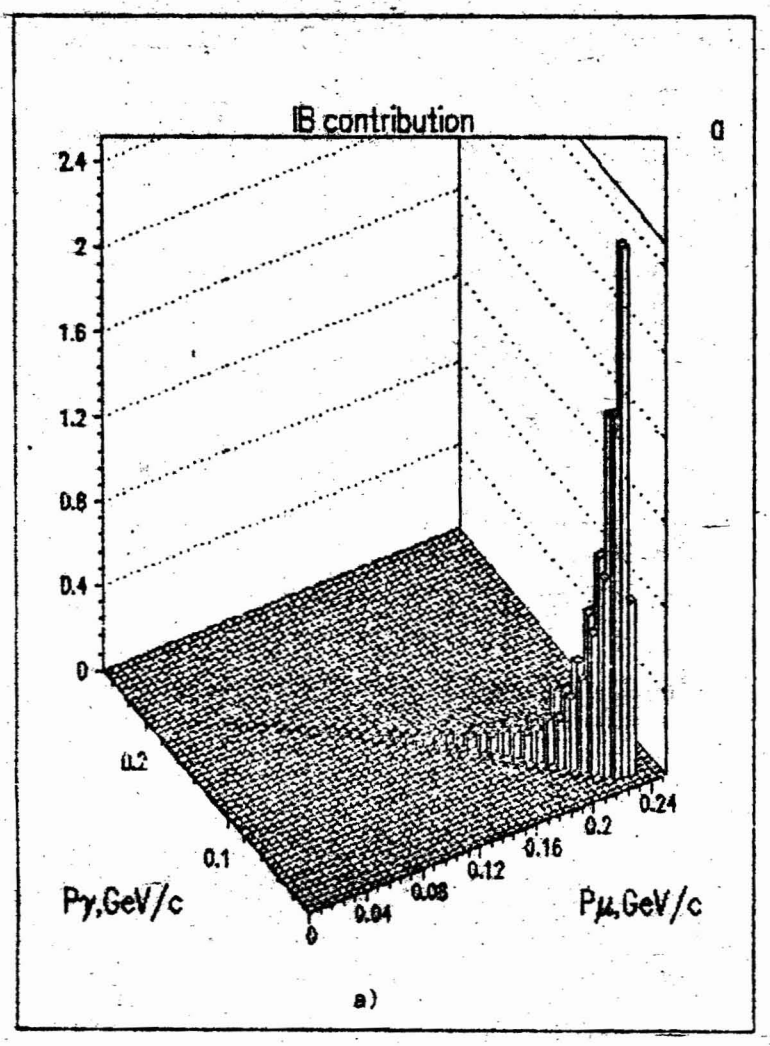


Fig. 5a-e. A two dimensional plot of the muon momentum p_μ vs the photon momentum p_γ in the kaon c.m.s. for the various $K^+ \to \mu^+ \nu \gamma$ decay terms.

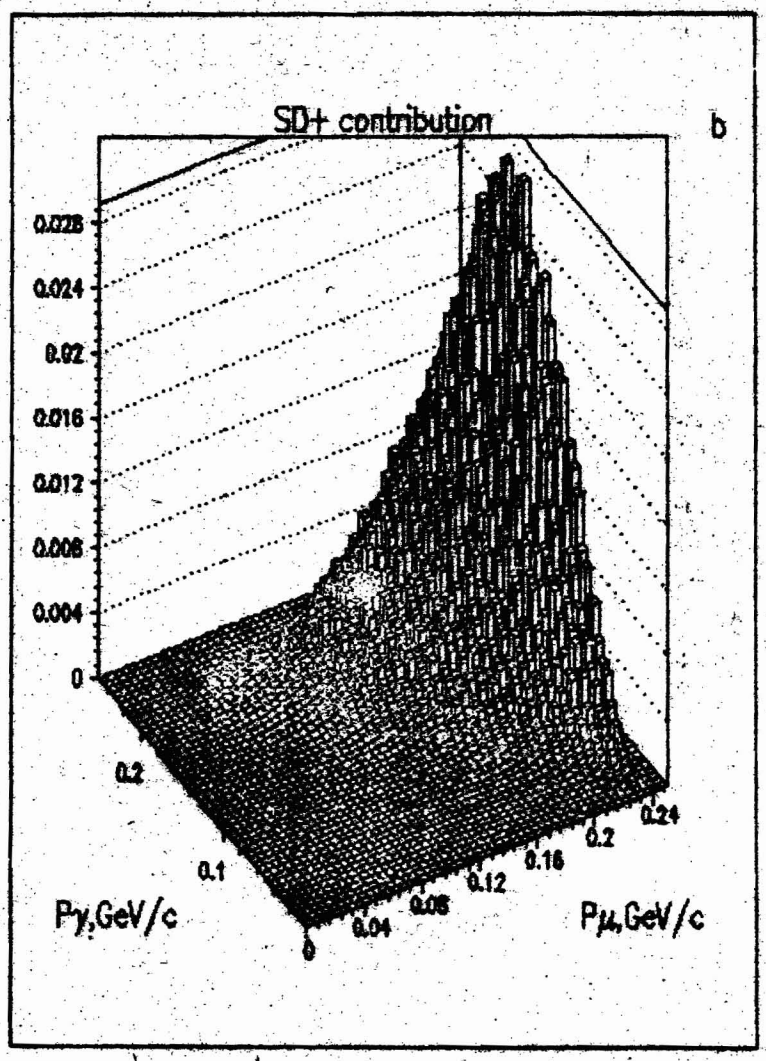
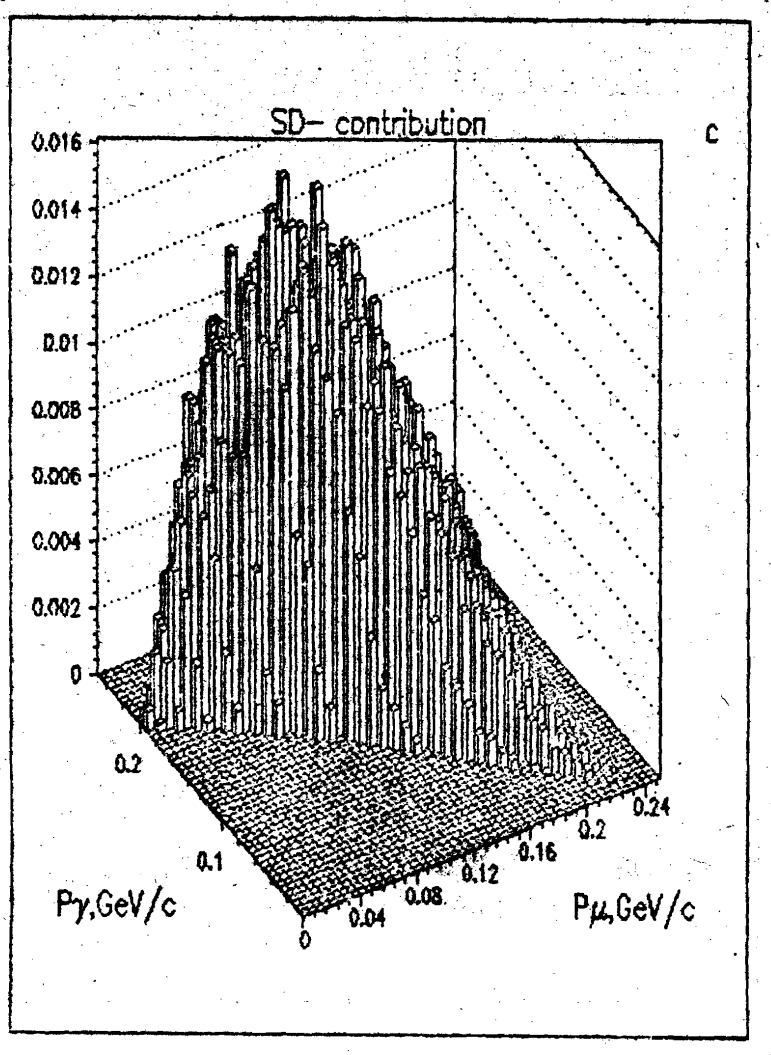

SD+ contribution
b
0.028
0.024
0.02
0.016
0.012
0.008
0.004
0
0.2
0.1
0
Pγ,GeV/c
0.04
0.08
0.12
0.16
0.2
0.24
Pμ,GeV/c

Fig. 5b


SD- contribution
c
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0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0.2
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0
Pγ,GeV/c
0.04
0.08
0.12
0.16
0.2
0.24
Pμ,GeV/c

Fig. 5c

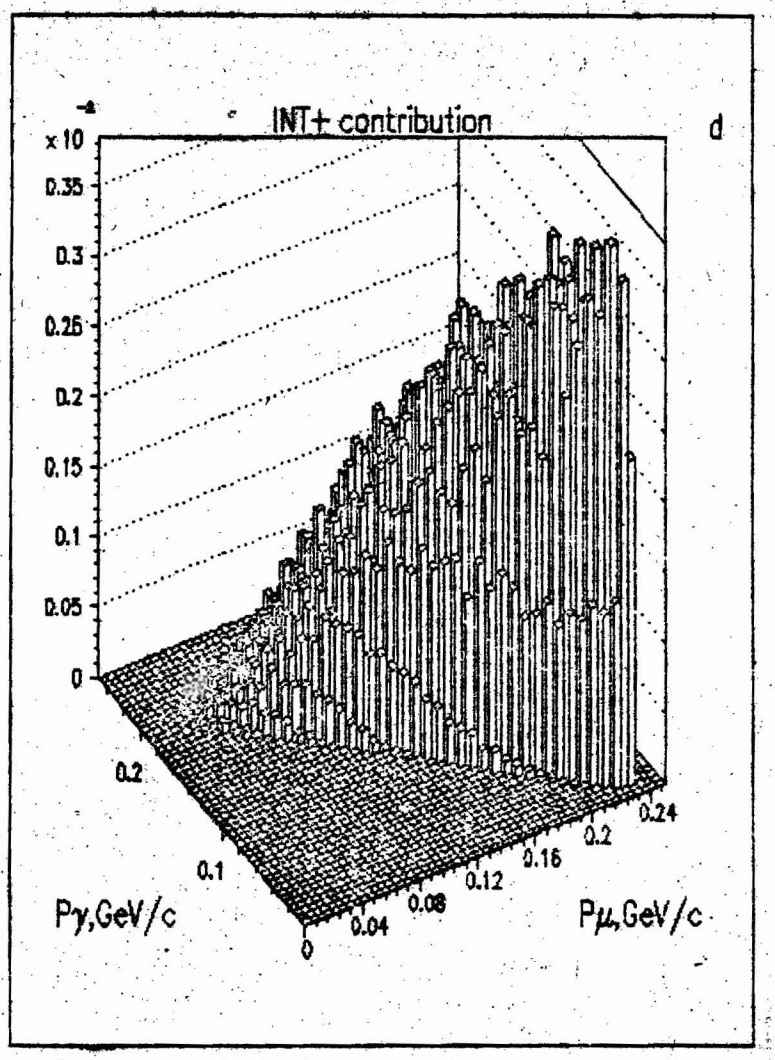
INT+ contribution
d
x 10
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.2
0.1
0
Pγ,GeV/c
0.04
0.08
0.12
0.16
0.2
0.24
Pμ,GeV/c

Fig. 5d

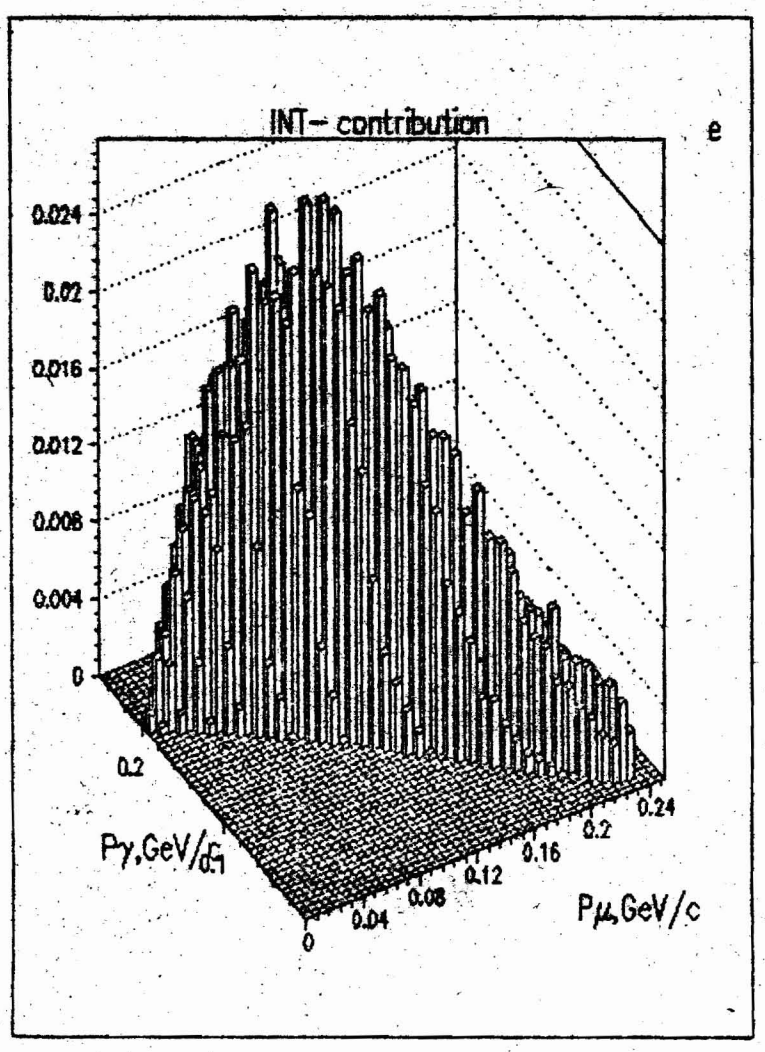
INT- contribution
e
0.024
0.02
0.016
0.012
0.008
0.004
0
0.2
Pγ,GeV/c
0
0.04
0.08
0.12
0.16
0.2
0.24
Pμ,GeV/c

Fig. 5e

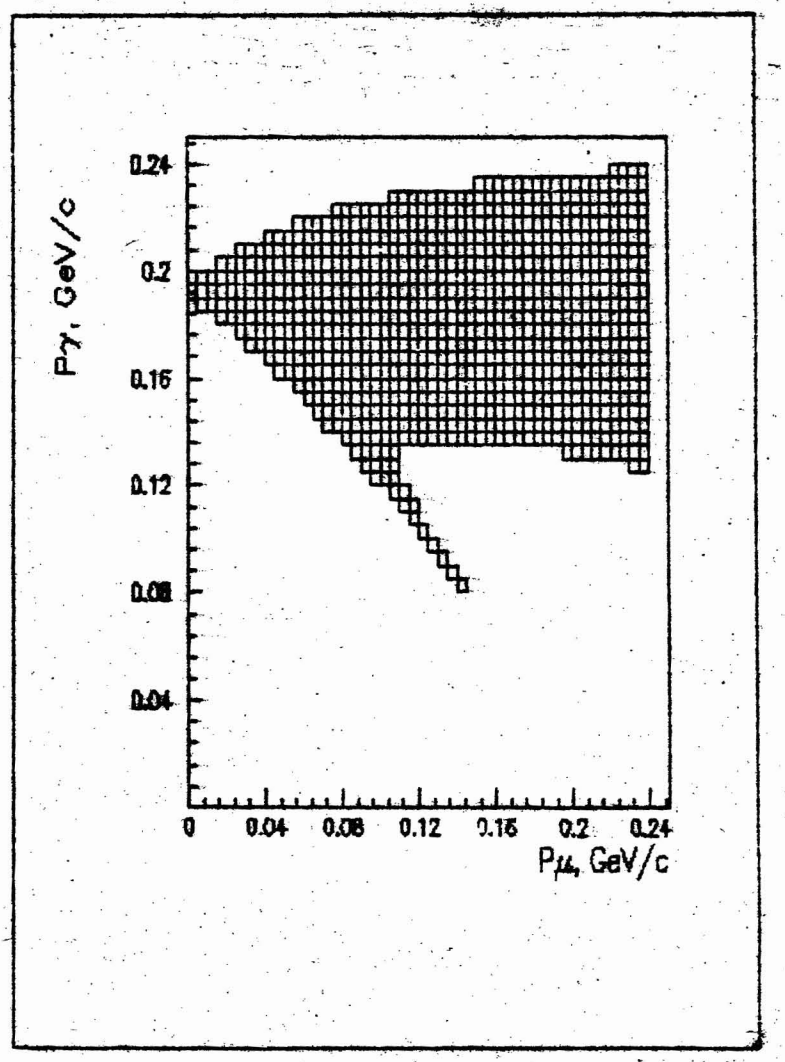

Fig.6. A p_μ-p_γ region for the search of SD_ and INT_ terms.

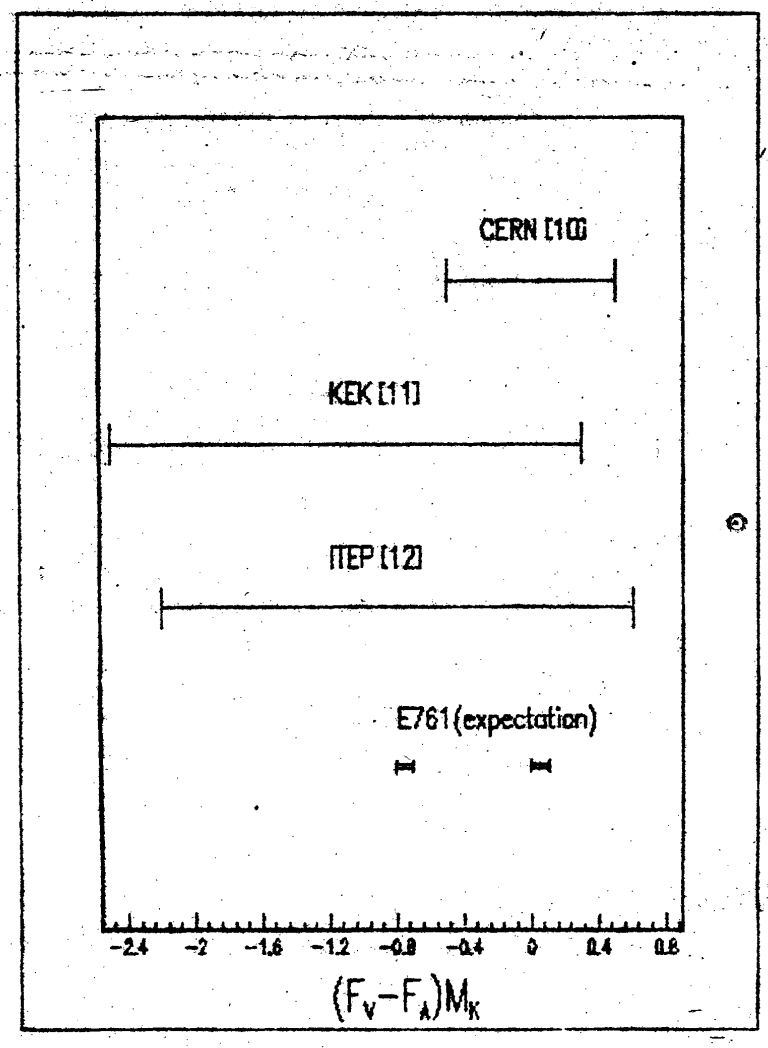

Fig.7. Estimations of values $(F_V-F_A)M_K$ from the previous experiments. The anticipated result of this experiment assuming the theoretical value [9] is also given.

REFERENCES

1. Sarker A.Q. // Phys.Rev. 1968. V.173. P.1749.
2. Rockmore R. // Phys.Rev. 1969. V.177. P.2573.
3. Carron N.J., Schult R.L. // Phys.Rev. 1970. V.D1. P.3171.
4. Milton K.A., Wada W.W. // Phys.Lett. 1981. V.98B. P.367.
5. Neville D.E. // Phys.Rev. 1961. V.124. P.2037.
6. Avakian E.Z. at al., JINR, P2-86-441, Dubna, 1986.
7. Smoes M.J. // Nucl.Phys. 1970. V.B20. P.237.
8. Bardin D.Yu., Bilenky S.M. // Yad.Fiz. 1972. V.16. P.557.
9. Donoghue J. Preprint UMHEP-329, 1990.
10. Heintze J. at.al. // Nucl.Phys. 1979. V.B149. P.365.
11. Akiba Y. at.al. // Phys.Rev. 1985. V.D32. P.2911.
12. Demidov V.S. at al., // Yad.Fiz. 1990. V.52. P.1595
13. M Foucher et al. // Phys.Rev.Lett. 1992. V.68. P.3004.
14. Particle Data Group: Phys.Rev. D 45. 1992

Демидов В.С.

О возможности измерения форм-факторов структурного излучения в распаде $K^+ \to \mu^+ \nu \gamma$ в эксперименте FERMILAB E761.

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