

Extraction of Kaon Formfactors from $K^- \rightarrow \mu^- \nu \gamma$ Decay at ISTR A+ Setup

V. A. Duk^{a*}

^a *Institute for Nuclear Research of RAS, Moscow, Russia*
INR RAS, 60-letiya Oktyabrya prospekt 7a, Moscow 117312, Russia

Abstract

The radiative decay $K^- \rightarrow \mu^- \nu \gamma$ has been studied at ISTR A+ setup in a new kinematic region. About 22K events of $K^- \rightarrow \mu^- \nu \gamma$ have been observed. The sign and value of $F_V - F_A$ have been measured for the first time. The result is $F_V - F_A = 0.21 \pm 0.04(stat) \pm 0.03(syst)$.

1 Introduction

Radiative kaon decays are dominated by long distance (low energy) physics. For low energy processes there are no direct predictions from SM and effective theories such as Chiral perturbation theory (χ PT) are used. χ PT gives quantitative predictions for most kaon decay modes. That is why radiative kaon decays provide a testing ground for χ PT. Moreover, these decays are sensitive to New Physics.

The decay $K^- \rightarrow \mu^- \nu \gamma$ is sensitive to hadronic weak currents in low-energy region. The decay amplitude includes two terms: internal bremsstrahlung (IB) and structure dependent term (SD). IB contains radiative corrections from $K^- \rightarrow \mu^- \nu$. SD allows to probe electroweak structure of kaon.

The differential decay rate can be written in terms of standard kinematic variables $x=2E_\gamma^*/M_k$ and $y = 2E_\mu^*/M_k$ (see [1] for details), E_γ^* being photon energy and E_μ^* muon energy in cms. It includes IB, SD^\pm parts and their interference INT^\pm . The SD^\pm and INT^\pm contributions are determined by two formfactors F_V and F_A .

The general formula for decay rate is as follows:

$$\begin{aligned} \frac{d\Gamma}{dx dy} = & A_{IB} f_{IB}(x, y) + A_{SD} [(F_V + F_A)^2 f_{SD^+}(x, y) + (F_V - F_A)^2 f_{SD^-}(x, y)] \\ & - A_{INT} [(F_V + F_A) f_{INT^+}(x, y) + (F_V - F_A) f_{INT^-}(x, y)] \end{aligned}$$

where

$$f_{IB}(x, y) = \left[\frac{1-y+r}{x^2(x+y-1-r)} \right] \left[x^2 + 2(1-x)(1-r) - \frac{2xr(1-r)}{x+y-1-r} \right],$$

$$f_{SD^+}(x, y) = [x + y - 1 - r] [(x + y - 1)(1 - x) - r],$$

$$f_{SD^-}(x, y) = [1 - y + r] [(1 - x)(1 - y) + r],$$

$$f_{INT^+}(x, y) = \left[\frac{1-y+r}{x(x+y-1-r)} \right] [(1-x)(1-x-y) + r],$$

*e-mail: Viacheslav.Duk@cern.ch

$$f_{INT-}(x, y) = \left[\frac{1-y+r}{x(x+y-1-r)} \right] [x^2 - (1-x)(1-x-y) - r],$$

$$\text{and } r = \left(\frac{M_\mu}{M_K} \right)^2, \quad A_{IB} = \Gamma_{K\mu 2} \frac{\alpha}{2\pi} \frac{1}{(1-r)^2}, \quad A_{SD} = \Gamma_{K\mu 2} \frac{\alpha}{8\pi} \frac{1}{r(1-r)^2} \left[\frac{M_K}{F_K} \right]^2, \quad A_{INT} = \Gamma_{K\mu 2} \frac{\alpha}{2\pi} \frac{1}{(1-r)^2} \frac{M_K}{F_K}.$$

In these formulae, α is the fine structure constant, F_K is K^+ decay constant ($F_K = 155.5 \pm 0.2 \pm 0.8 \pm 0.2 \text{ MeV}$ [2]) and $\Gamma_{K\mu 2}$ is $K\mu 2$ decay width. Dalitz-plot distributions for different terms are shown in fig. 1÷4.

$F_V \pm F_A$ are calculated within χ PT ($O(p^4)$ [1], $O(p^6)$ [3]) and LFQM model [4]. In general, F_V and F_A depend on $q^2 = (P_K - P_\gamma)^2 = M_K^2(1-x)$. In the $O(p^4)$ χ PT they are constant and $F_V + F_A = 0.137$, $F_V - F_A = 0.052$. We will initially assume F_V and F_A constant and then test for their dependence on q^2 .

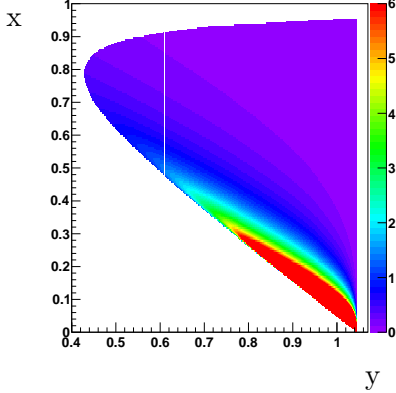


Figure 1: IB

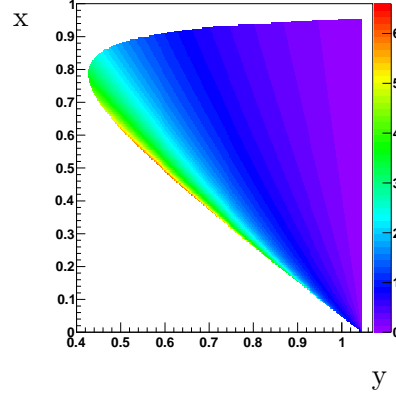


Figure 2: INT-

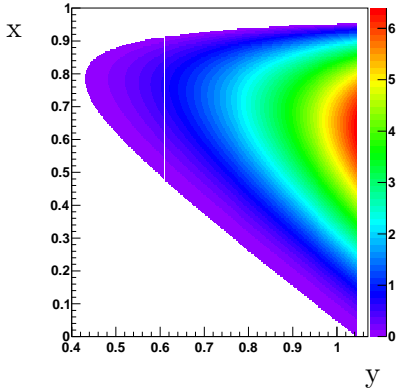


Figure 3: SD+

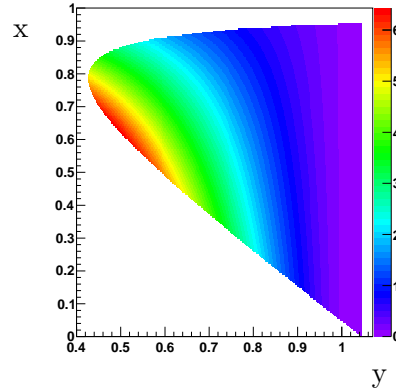


Figure 4: SD-

Experimentally, the decay $K^- \rightarrow \mu^- \nu_\mu \gamma$ was studied mostly in the IB dominated region (see [5],[6],[7]). There was only one formfactor measurement in E787 experiment [8]. In this study, SD+ term was extracted and $|F_V + F_A|$ was obtained to be $|F_V + F_A| = 0.165 \pm 0.007(stat) \pm 0.011(syst)$. Also $F_V - F_A$ was constrained: $-0.04 < F_V - F_A < 0.24$. $F_V - F_A$ was measured by E865 experiment in $K \rightarrow \mu \nu e^+ e^-$ decay [9]: $F_V - F_A = 0.077 \pm 0.028$. The goal of our study is to measure $K \rightarrow \mu \nu \gamma$ decay in the kinematic region where INT- term (and hence $F_V - F_A$) can be extracted.

2 ISTR A+ experiment

2.1 Experimental setup

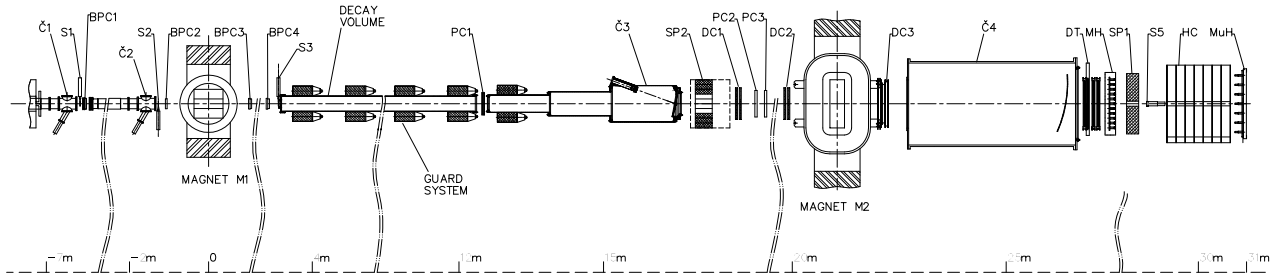


Figure 5: Elevation view of the ISTR A+ detector.

The experiment was performed at the IHEP 70 GeV proton synchrotron U-70. The experimental setup ISTR A+ (fig. 5) was described in some details in [10]. The setup was located in the negative unseparated secondary beam. The beam momentum in the measurements was ~ 26 GeV with $\Delta p/p \sim 1.5\%$. The admixture of K^- in the beam was $\sim 3\%$. The beam intensity was $\sim 3 \cdot 10^6$ per 1.9 sec U-70 spill. The track of beam particle deflected by M_1 was measured by $BPC_1 \div BPC_4$ (1mm step multiwire chambers), the kaon identification was done by $\check{C}_0 \div \check{C}_2$ threshold \check{C} -counters. A 9 meter long vacuum decay volume was surrounded by 8 lead glass rings $LG_1 \div LG_8$ used to veto low energy photons. SP_2 was a lead glass calorimeter to detect/veto large angle photons. The decay products deflected in M_2 with 1Tm field integral were measured by $PC_1 \div PC_3$ (2mm step proportional chambers); $DC_1 \div DC_3$ (1cm cell drift chambers) and finally by 2cm diameter drift tubes $DT_1 \div DT_4$. Wide aperture threshold Cerenkov counters \check{C}_3 , \check{C}_4 were filled with He and were not used in the measurements. Nevertheless \check{C}_3 was used as the extension of the decay volume. SP_1 (ECAL) was a 576-cell lead glass calorimeter, followed by HC (HCAL) - a scintillator-iron sampling hadron calorimeter. HC was subdivided into 7 longitudinal sections 7×7 cells each. MH was a 11×11 cell scintillating hodoscope used to improve the time resolution of the tracking system, MuH was a 7×7 cell muon hodoscope.

The trigger was provided by $S_1 \div S_3$, S_5 scintillation counters, $\check{C}_0 \div \check{C}_2$ Cerenkov counters, analog sum of amplitudes from the last dinodes of the SP_1 : $T_0 = S_1 \cdot S_2 \cdot S_3 \cdot \check{C}_0 \cdot \check{C}_1 \cdot \check{C}_2 \cdot \bar{S}_5 \cdot \Sigma(SP_1)$, here \bar{S}_5 was a counter downstream the setup at the beam focus; $\Sigma(SP_1)$ - a requirement for the analog sum of ECAL amplitudes to be above ~ 3 GeV. The last requirement served to suppress the $K \rightarrow \mu\nu$ decay. About $\sim 10\%$ events were recorded with a different trigger: $T_1 = S_1 \cdot S_2 \cdot S_3 \cdot \check{C}_0 \cdot \check{C}_1 \cdot \check{C}_2 \cdot \bar{S}_5$. This prescaled trigger allowed to calculate trigger efficiency as a function of the energy released in ECAL.

2.2 Data and MC samples

We use high-statistics data collected in Winter 2001 run. About 332M events were stored on tapes. This statistics was complemented by 200M MC events generated with Geant3 [11]. The MC generation included realistic description of all ISTR A+ detectors.

3 Event selection

3.1 Selection criteria and general cuts

The decay is identified as follows: one primary track (kaon), one negatively charged secondary track, μ flag; one shower in ECAL not associated with the charged track. Muon identification

using ECAL and HCAL is described in our previous papers ([12],[13]).

Several cuts are applied to clean the data:

- number of beam and decay tracks in both X and Y projections is equal to 1;
- CL of primary tracks in both X and Y projections must be greater than 10^{-2} ;
- CL of decay tracks is greater than 0.1 (decay-X) and 0.15 (decay-Y);
- the angle between primary (kaon) and secondary (muon) track is greater than 2 mrad.

The last cut eliminates most of undecayed beam particles. The quality of decay track (described quantitatively by CL) is worse than that of beam track because of multiple scattering and detector resolution.

Cuts containing photon energy include:

- Gamma energy in kaon rest frame is greater than 10 MeV;
- no photons in SP₂ calorimeter (energy threshold is 0.5 GeV for total energy release);
- no photons in GS.

For vertex characteristics we have the following requirements:

- z-coordinate must be within the interval $400 < z < 1600\text{cm}$;
- $(-3) < x_{vtx} < 3\text{cm}$;
- $(-2) < y_{vtx} < 6\text{cm}$;
- CL of general vertex fit is greater than 10^{-2} .

Additional cuts are applied to suppress backgrounds:

- number of hits in matrix hodoscope (MH) is less than 3;
- missing momentum does not point to the ECAL central hole (this cut effectively rejects $K\pi 2$ background since missing particle is the lost photon from $\pi^0 \rightarrow \gamma\gamma$ in this case);

3.2 Trigger efficiency

As T_0 trigger described in Section 2 contains energy threshold in SP₁ the trigger efficiency as a function of energy released in ECAL should be found using events with T_1 trigger: $\epsilon_{trg} = (T_1 \cap T_0) / T_1$. Trigger curve is shown in the fig. 6. The fit is done using Fermi function. For the further analysis only events with T_0 are kept and these events are weighted by the factor of $1/\epsilon_{trg}$.

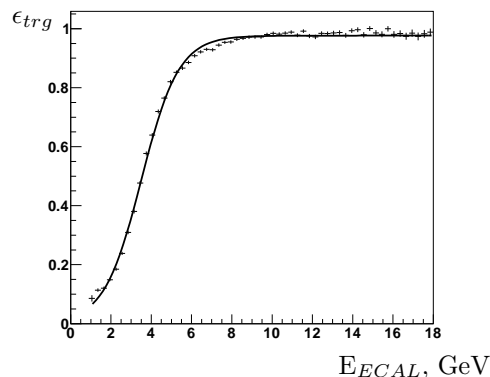


Figure 6: T_0 trigger efficiency

4 Signal extraction

Distribution over $M(\mu\nu\gamma)$ is used for signal observation. $M^2(\mu\nu\gamma) = (P_\mu + P_\nu + P_\gamma)^2$ where P_μ, P_ν, P_γ are 4-momenta of corresponding particles; missing mass m_ν is supposed to be equal

to 0 so that $\vec{p}_\nu = \vec{p}_K - \vec{p}_\mu - \vec{p}_\gamma$; $E_\nu = |\vec{p}_\nu|$. $M(\mu\nu\gamma)$ peaks at K^- mass for the signal. Main background comes from 2 decay modes: $K^- \rightarrow \mu^- \nu \pi^0 (K\mu 3)$ and $K^- \rightarrow \pi^- \pi^0 (K\pi 2)$ with one gamma lost from $\pi^0 \rightarrow \gamma\gamma$ and π misidentified as μ . Dalits-plot distributions for $K\mu 3$ and $K\pi 2$ are shown in fig. 7, 8.

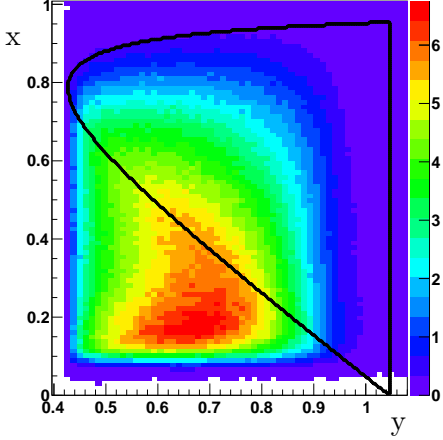


Figure 7: Dalitz-plot density for $K\mu 3$ bkg

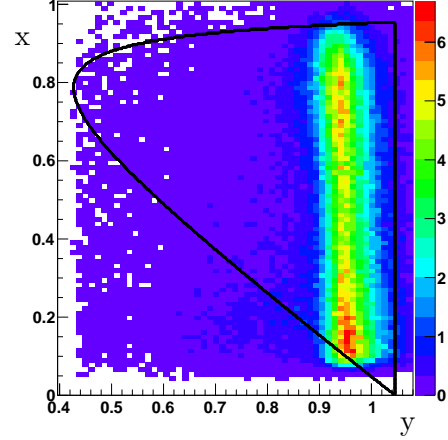


Figure 8: Dalitz-plot density for $K\pi 2$ bkg

4.1 Signal extraction procedure

The procedure starts with dividing all kinematic (x,y) region into stripes on x (x-stripes). The stripe width is $\Delta x = 0.05$ ($\Delta E_\gamma^* \sim 24 MeV$). In every x-stripe we put a cut on y: $y_{min} < y < y_{max}$. y_{min} and y_{max} are selected from the maximization of signal significance defined as $\frac{S}{\sqrt{S+B}}$.

Besides distributions over $M(\mu\nu\gamma)$ and y, we use $\cos \theta_{\mu\gamma}^*$ for the signal extraction, $\theta_{\mu\gamma}^*$ being the angle between \vec{p}_μ and \vec{p}_γ in c.m.s. We put a cut on $\cos \theta_{\mu\gamma}^*$ to reject background in those stripes where distributions over $\cos \theta_{\mu\gamma}^*$ for signal and background differ a lot.

Finally for each x-stripe we obtain events with cuts on y and $\cos \theta_{\mu\gamma}^*$. Now we construct $M(\mu\nu\gamma)$ which will be used for the fit. Fitting $M(\mu\nu\gamma)$ alone is not sufficient because in some stripes distributions for signal and background are very similar. Also it would be difficult to distinguish between two backgrounds - $K\mu 3$ and $K\pi 2$. That is why we take three histograms (y; $\cos \theta_{\mu\gamma}^*$ with cut on y; $M(\mu\nu\gamma)$ with cuts on y and $\cos \theta_{\mu\gamma}^*$) and fit them simultaneously. Both signal and background shapes are taken from MC. MC histograms are smoothed and the result is stored as f(x) function (x= $M(\mu\nu\gamma)$, y or $\cos \theta_{\mu\gamma}^*$). For better fit we allow these functions to be slightly widen and shifted. We do it by using $f(k*x+b)$ instead of $f(x)$ in the fit, where fit parameters k and b are the same for signal and background and are different for $M(\mu\nu\gamma)$, y and $\cos \theta_{\mu\gamma}^*$. In fig. 9 and 10 extra width k and extra shift b for y-histogram are shown. For all selected x-stripes $k \sim 1$ and $b \sim 0$, i.e. our MC describes data properly.

The simultaneous fit gives signal event number in each x-stripe. As we use the same data several times we should take care about correct estimation of statistical error:

- do simultaneous fit of three histograms and obtain $\{p_i\}$ - best parameter values (they correspond to global χ^2 minimum);
- take $\{p_i\}$ as initial values and perform χ^2/ndf and error estimation for one histogram $M(\mu\nu\gamma)$ using MINOS program.

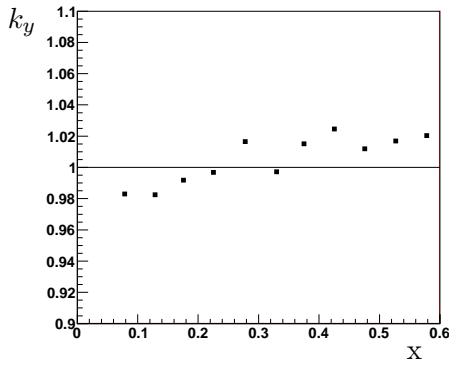


Figure 9: Extra width k_y vs x

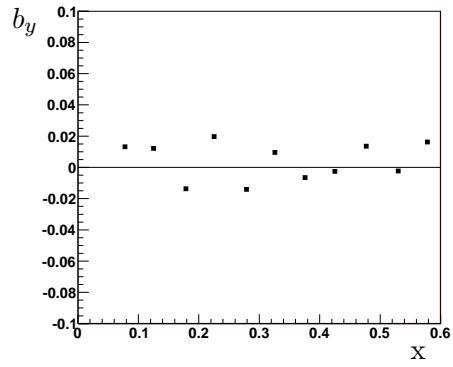


Figure 10: Extra shift b_y vs x

4.2 Selected kinematic region

For further analysis we have selected eleven x-strips in the following region: $0.05 < x < 0.6$ ($13MeV < E_\gamma^* < 150MeV$). The twelfth x-stripe is used for systematics study only. Cuts on y and $\cos \theta_{\mu\gamma}^*$ are summarized in table.1.

strip	cut on x	cut on y	Δy	cut on $\cos \theta_{\mu\gamma}^*$
01	$0.05 < x < 0.1$	$0.9 \div 1.1$	0.2	> -0.8
02	$0.1 < x < 0.15$	$0.9 \div 1.1$	0.2	> -0.8
03	$0.15 < x < 0.2$	$0.85 \div 1.$	0.15	> -0.8
04	$0.2 < x < 0.25$	$0.8 \div 0.95$	0.15	> -0.2
05	$0.25 < x < 0.3$	$0.75 \div 0.9$	0.15	> -0.3
06	$0.3 < x < 0.35$	$0.72 \div 0.87$	0.15	> -0.4
07	$0.35 < x < 0.4$	$0.65 \div 0.85$	0.2	> -0.3
08	$0.4 < x < 0.45$	$0.62 \div 0.85$	0.23	> -0.5
09	$0.45 < x < 0.5$	$0.57 \div 0.8$	0.23	> -0.7
10	$0.5 < x < 0.55$	$0.52 \div 0.75$	0.23	-
11	$0.55 < x < 0.6$	$0.48 \div 0.7$	0.22	-

Table 1: Cuts on y and $\cos \theta_{\mu\gamma}^*$ in x-strips

The y -width changes from stripe to stripe, in average $\Delta y \sim 0.2$. Our kinematic region is sensitive to INT- term (fig. 11) and complementary to that of previous experiments [8],[5] (fig. 12). Stripe borders are slightly out of allowed kinematic region because of resolution.

Results of simultaneous fit for stripes #2 ($0.1 < x < 0.15$) and #9 ($0.45 < x < 0.5$) are shown in fig. 13, 14. The total number of unweighted signal events is $\sim 22K$.

5 $F_V - F_A$ measurement

For each x-stripe we have experimental event number N_{exp} from fitting the data and IB event number N_{IB} from MC (see fig. 15). Then we plot N_{exp}/N_{IB} as a function of x where each bin corresponds to a certain x-stripe (see fig. 16).

For IB only we would have $N_{exp}/N_{IB} \approx 1$. It is the case for small x where IB is dominated and INT- is negligible. For large x we see that N_{exp} also contains negative interference term. We fit N_{exp}/N_{IB} distribution with $(f_{IB}(x) - f_{INT-}(x, p))/f_{IB}(x)$ where f_{IB} and f_{INT-} give MC event number for a certain x-stripe and fit parameter p equals to $F_V - F_A$ (F_V and F_A are initially assumed to be constant). The result of the final fit is as follows: $F_V - F_A = 0.21 \pm 0.04(stat)$. Number of 'missing events' due to negative INT⁻ term is 1271 which is $\sim 2.6\%$ of expected IB contribution (49481 weighted events).

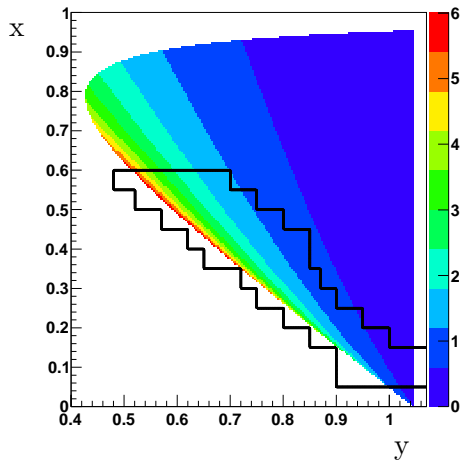


Figure 11: INT- dalitz-plot density and selected kinematic region

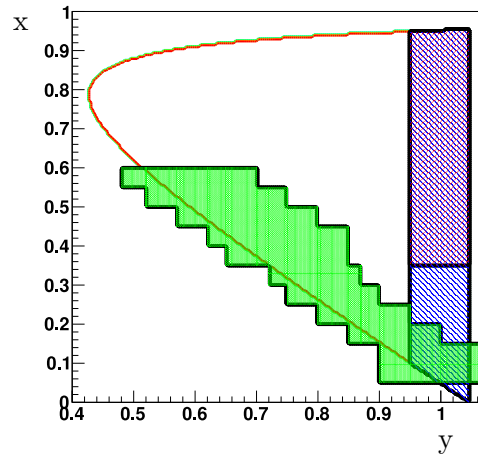


Figure 12: ISTR A+(green); BNL E787(red hatch); KEK-104(blue hatch)

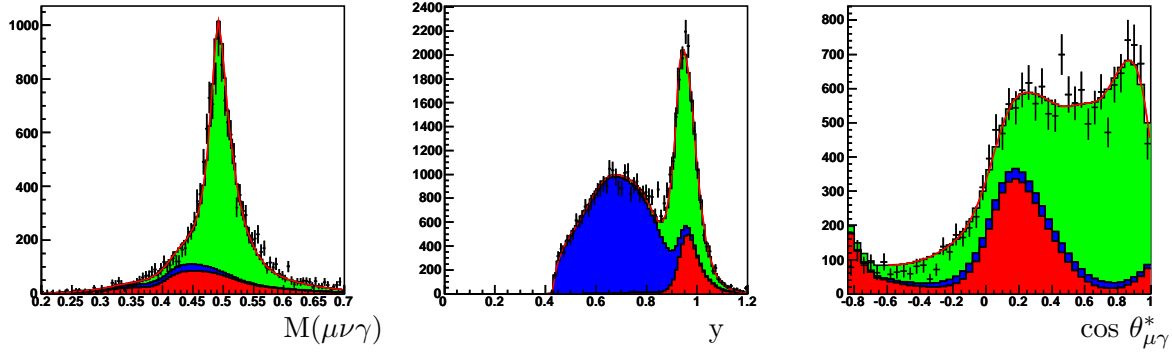


Figure 13: Simultaneous fit in stripe 2: $M(\mu\nu\gamma)$, y and $\cos \theta_{\mu\gamma}^*$. Points with errors - data, blue - $K\mu 3$, red - $K\pi 2$, green - signal, red line - signal+background. $\chi^2/\text{ndf}=111.5/95$ (for mass histogram only, see text).

6 Systematic error estimation

The main potential sources of systematic error are:

- possible non-ideal description of signal/background shape in the simultaneous fit;
- cut on x (i.e. number of selected x -stripes);
- cut on y in x -stripes;
- cut on z -coordinate of the vertex.

Each source is investigated separately and errors are considered to be independent.

Possible non-ideal description of signal/background shape in the simultaneous fit. For estimation of shape systematics we scale errors in each bin of the final fit of fig. 16 proportionally to $\sqrt{\chi^2}$. Then we repeat final fit. New value of $F_V - F_A$ is consistent with the main one and the fit error is larger: $\sigma_{fit} \sim 5 \times 10^{-2}$. We treat σ_{fit} as follows: $\sigma_{fit} = \sqrt{\sigma_{stat}^2 + \sigma_{syst,fit}^2}$ with $\sigma_{syst,fit}$ being systematical error caused by non-ideal shape of signal and background distributions: $\sigma_{syst,fit} \sim 3 \times 10^{-2}$.

Cut on x . Each x -stripe has the width $\Delta x=0.05$. By adding/removing stripes involved in the fit on the left(right) border and repeating final fit we can see how $F_V - F_A$ depends on the x -cut value. For the left border, we take results of 3 fits which include stripes 1÷11(main fit),

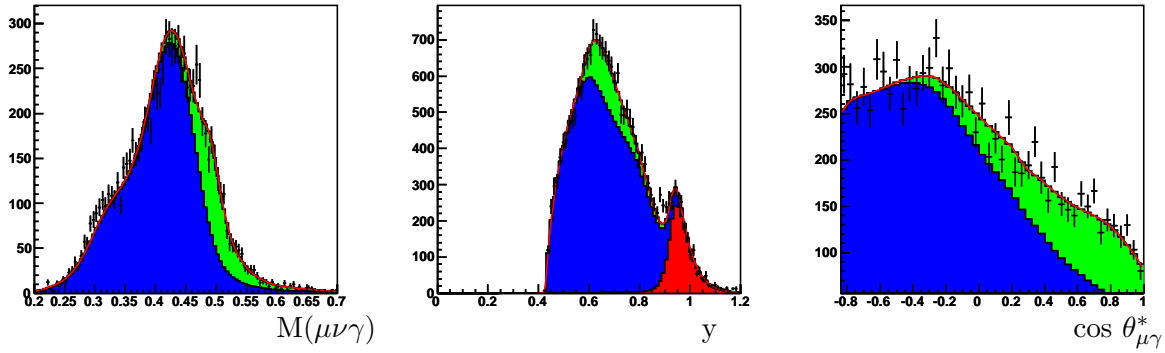


Figure 14: Simultaneous fit in stripe 9: $M(\mu\nu\gamma)$, y and $\cos \theta_{\mu\gamma}^*$. Points with errors - data, blue - $K\mu 3$, red - $K\pi 2$, green - signal, red line - signal+background. $\chi^2/\text{ndf}=140.0/100$ (for mass histogram only, see text).

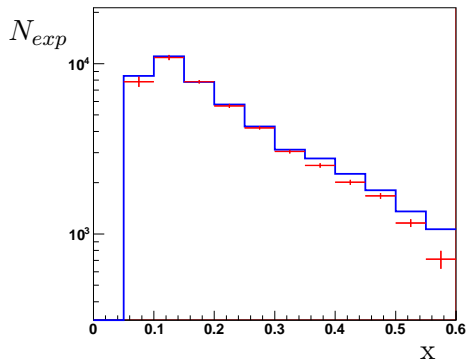


Figure 15: x-spectrum. Red points - data, blue histogram - IB

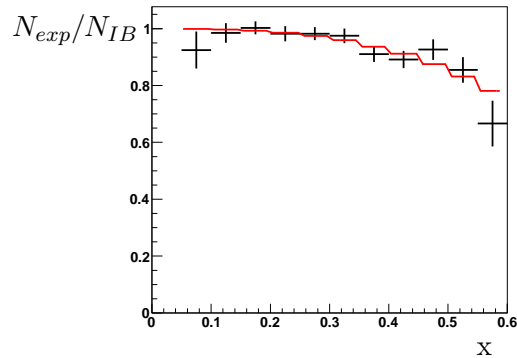


Figure 16: N_{exp}/N_{IB} for x-stripes and final fit. $\chi^2/\text{ndf}=7.8/9$

$2\div 11$ and $3\div 11$. For the right border, we choose fits including stripes $1\div 10$, $1\div 11$ (main fit), $1\div 12$.

The resulting plots $F_V - F_A$ vs x-cut are shown in fig. 17 and 18. For the conservative estimate of systematics we fit these plots with straight lines. The line slope multiplied by the resolution in x (which is taken from MC) gives systematic error of this cut. The systematic error of the right border is found to be $\sim 1.2 \times 10^{-2}$ and that of the left border is negligible.

Cut on y in x-stripes. To investigate this source of systematics we choose cut on y in a different way: instead of using significance we select events inside FWHM in y-distribution for signal MC. Such cuts on y are stronger than those made using significance. We redo simultaneous fit in x-stripes and final fit. The obtained result is consistent with the main one. No systematics is found here.

Cut on z-coordinate of the vertex. To study this systematics we divide events into two groups - with $z < 1100$ cm and $z > 1100$ cm. The events with $z < 1100$ cm use PC1 in the decay track reconstruction while events with $z > 1100$ cm do not. Besides that the second group of events has the vertex inside the decay volume filled with He. It could be a possible source of systematics. Repeating the whole procedure (simultaneous fit in x-stripes and final fit) we obtain two values for $F_V - F_A$ which are averaged. The obtained values are compatible. No systematics is found here.

Total systematic error. Now we quadratically sum all sources supposing the errors to be

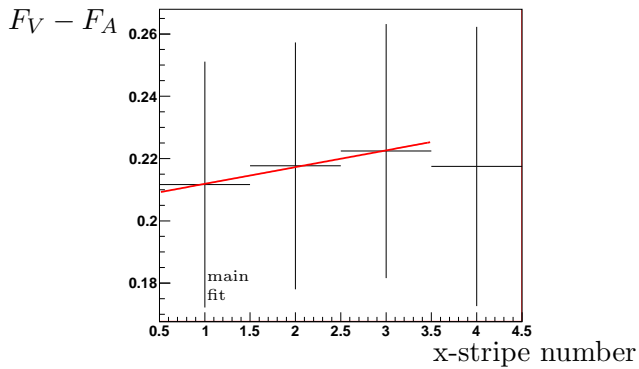


Figure 17: Systematics of cut on x. Left border

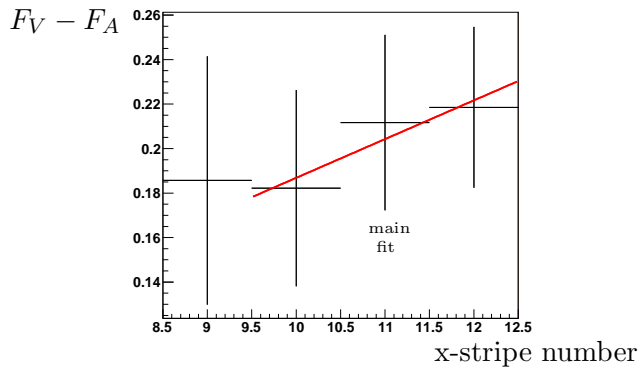


Figure 18: Systematics of cut on x. Right border

independent and obtain $\epsilon_{syst} \sim 3.2 \times 10^{-2}$.

7 Final result

With this estimation of systematic error we finally get our result: $F_V - F_A = 0.21 \pm 0.04(stat) \pm 0.03(syst)$. It is $\sim 3\sigma$ larger than theoretical prediction within χPT at $O(p^4)$.

The $O(p^6)$ χPT gives linear dependence of F_V and F_A on q^2 (see [3]) and hence on x . We use F_V and F_A parametrization given in [14]: $F_V = F_V(0) [1 + \lambda(1 - x)]$, $F_A = \text{const}$. This theoretical prediction was tested in three ways. First, we take both F_V and F_A from $O(p^6)$ χPT ($F_V(0) = 0.082$, $F_A = 0.034$, $\lambda = 0.4$) and do the final fit. χ^2 of this fit is 21.1/10 ($\sim 2.5\sigma$ from $\chi^2 = 1$). Second, we take $F_V(0)$ and F_A from $O(p^6)$ χPT and take λ as a fit parameter. It gives $\lambda = 4.0 \pm 1.0$ with $\chi^2 = 8.8/9$ (fig. 19). And finally we fix $F_V(0)$ from $O(p^6)$ χPT and take λ and F_A as fit parameters. Correlation between them is shown in fig. 21. Theoretical prediction is slightly out of 3σ -ellipse.

In LFQM, F_V and F_A depend on q^2 in a complicated way (see [4]). Final fit is shown in fig. 20. LFQM is disfavored ($\sim 3\sigma$ from $\chi^2 = 1$) although can not be excluded.

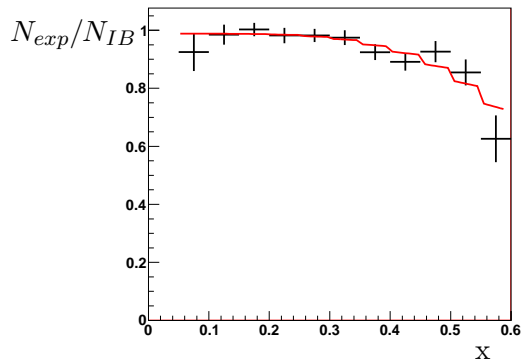


Figure 19: χPT $O(p^6)$ fit, $F_V(0)$ and F_A taken from theory. $\chi^2/ndf = 8.8/9$

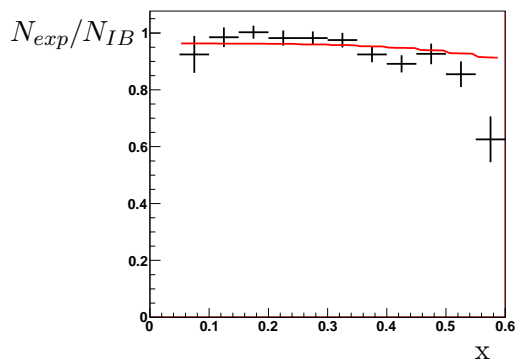


Figure 20: LFQM fit, F_V and F_A taken from theory. $\chi^2/ndf = 24.1/10$

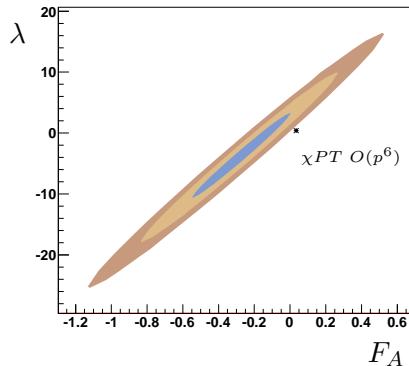


Figure 21: $\chi PT O(p^6)$ fit, $F_V(0)$ taken from theory. $\chi^2/ndf = 7.5/8$.

8 Conclusions

The radiative decay $K^- \rightarrow \mu^- \nu_\mu \gamma$ has been studied using in-flight decays at ISTRA+ setup. About 22K events of $K^- \rightarrow \mu^- \nu_\mu \gamma$ (it is the largest statistics for this decay) have been found in a new kinematic region. The negative INT⁻ term has been observed and as a result $F_V - F_A$ has been measured: $F_V - F_A = 0.21 \pm 0.04(stat) \pm 0.03(syst)$. The result is $\sim 3\sigma$ above $O(p^4)$ χPT prediction.

An alternative analysis done by our collaboration is presented in [15]. The results are slightly different because of additional systematics in the cited paper. This systematics comes from adding polynom-like background and is very difficult to be correctly estimated.

The author would like to thank C.Q. Geng and E. Goudzovsky for the code plotting formfactors in LFQM and V.F.Obraztsov for numerous discussions. The work is supported by Russian Foundation for Basic Research (grants 10-02-00330 and 08-02-91016).

References

- [1] J.Bijnens, G.Ecker and J.Gasser, Nucl.Phys. B396, 81 (1993); J.Bijnens et al., “Semileptonic kaon decays”, 2nd DAPHNE Physics Handbook, 315 (1994).
- [2] C.Amsler et al. Particle Data Group. Phys.Lett.B667 (2008) 1.
- [3] C.Q.Geng et al. Nucl.Phys. B684 (2004) 281-317; hep-ph/0306165.
- [4] Chuan-Hung Chen et al. Phys.Rev.D77:014004,2008; hep-ph/0710.2971.
- [5] Y.Akiba et al. Phys.Rev.D32:2911,1985.
- [6] V.S.Demidov et al. Sov.J.Nucl.Phys.52:1006-1011,1990, Yad.Fiz.52:1595-1604,1990.
- [7] V.V.Barmin et al. Sov.J.Nucl.Phys.47:643,1988, Yad.Fiz.47:1011-1014,1988.
- [8] S.C.Adler et al. Phys.Rev.Lett.85:2256-2259,2000; hep-ex/0003019.
- [9] A.A.Poblaguev et al. Phys.Rev.Lett.89(2002) 061803.
- [10] V.N.Bolotov et al. IHEP preprint 8-98,1998.
- [11] R.Brun et al. CERN-DD/EE/84-1.
- [12] I.V.Ajinenko et al. Phys.Atom.Nucl. 66(2003) 105; Yad.Fiz. 66 (2003) 107.

- [13] O.P.Yushchenko et al. Phys.Lett. B581 (2004) 31.
- [14] F.Ambrosino et al. Eur. Phys. J. C64 (2009) 627.
- [15] O.Tchikilev et al. IHEP-2008-27, Jan 2010. 15pp. hep-ex/1001.0374.