

A New Measurement of the Radiative K_{e3} Branching Ratio and Photon Spectrum

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We present a preliminary report on a new measurement of the radiative K_{e3} branching ratio and the first study of the photon spectrum in this decay. We find $\text{BR}(K_{e3\gamma}, E_\gamma^* > 30 \text{ GeV}, \theta_{e\gamma}^* > 20^\circ) / \text{BR}(K_{e3}) = 0.911 \pm 0.009(\text{stat.})_{-0.010}^{+0.021}(\text{syst.})\%$. Our measurement of the spectrum is consistent with inner bremsstrahlung only as the source of photons at the 2σ level.

A good understanding of radiative K_{e3} ($K_L \rightarrow \pi^\pm e^\mp \nu_e \gamma$) decays is important for many analyses in precision neutral kaon experiments. The decay is interesting in its own right as a test of Current Algebra (CA) and Chiral Perturbation Theory (χ PT) models of kaon structure. These models predict the size of the direct emission (DE) component, where the photon comes directly from the decay vertex, with respect to the dominant internal bremsstrahlung (IB) component, where the photon comes from one of the external particles. CA predicts a DE component of about 1% [1], whereas χ PT predicts a smaller DE component at the tenth of a percent level [3].

The measurement described here was performed using the KTeV detector at Fermilab, shown in Figure 1, which was designed to measure ϵ'/ϵ . Two nearly parallel beams of K^0 are produced by the 800 GeV Tevatron proton beam on a Beryllium target, with collimators well upstream of the decay region allowing the K_S component to die away. (The K_S regenerator used in ϵ'/ϵ was removed for this data.) Decay products are analyzed with a spectrometer consisting of four drift chambers and an analysis magnet. Following the spectrometer is a pure CsI electromagnetic calorimeter and a muon filter.

The strategy used in the analysis is to identify an inclusive K_{e3} sample, then identify a subsample containing one photon. The K_{e3} sample is defined

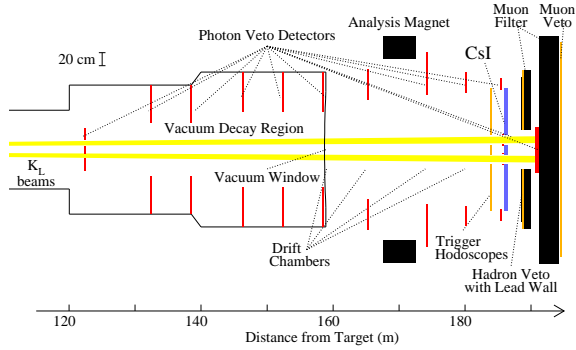


Fig. 1. The KTeV Detector

by requiring exactly two tracks in the spectrometer. The X and Y projections of the tracks are matched using clusters in the calorimeter, implying one cluster per track. Particle identification is performed by comparing the momentum in the spectrometer with the energy in the calorimeter. The electron must have $0.95 < E/P < 1.1$, the pion, $E/P < 0.7$. The momentum of each track must be above 7 GeV to make the muon filter efficient, and hits in the muon filter, or any other veto detector, kill the event. Kinetically disallowed events are removed as well. Fiducial cuts are placed on all tracks and clusters to restrict events to well understood parts of the detector. $K_{\pi 3}$ background events are eliminated by removing kinematically allowed events under the $K_{\pi 3}$ ansatz. The two-fold ambiguity in the reconstructed kaon momentum is resolved by taking the more likely solution for a given pair using MC generated distributions for allowed solution pairs.

With the inclusive K_{e3} sample in hand, a subsample of events with one photon candidate is isolated. A photon candidate appears as a cluster in the calorimeter unconnected with a track. The cluster must be more than 8 cm away from the electron and 40 cm away from the pion, to avoid fake extra clusters caused by shower fluctuations, which for pions especially, are poorly understood. The cluster must have an energy of 3 GeV, and pass a shape χ^2 cut for being a cluster from a single, electromagnetic shower. There must be only one cluster satisfying a looser set of candidate cuts (30 cm from the pion and 1 GeV on the energy). The difference in the definition of clusters for the final photon sample and for vetoing an event leads to a correction, as the MC veto rate is lower than observed in data.

The data for this sample was taken at a low rate reducing the problem of accidental photons. The effect is still important however, so an accidental trigger was used to sample the state of the detector at arbitrary times.

These events were overlaid on MC generated events to accurately model the data. In all, accidentals contribute about 4% to the photonic subsample.

It has become customary to cut on the photon energy in the kaon center of momentum frame (CM) and on the angle between the photon and the electron in that frame. The first cut is necessary since the radiative branching ratio is IR divergent in the photon energy, yet experiments are always limited by detection efficiency to some minimum energy. The second cut removes external bremsstrahlung radiation which is very highly correlated with the electron direction. Standard cuts at 30 MeV and 20 degrees are used, though KTeV is sensitive to significantly lower values in both cases.

The measured branching ratio is simply defined

$$\begin{aligned} \frac{\Gamma(K_{e3\gamma}, E_\gamma^* > 30 \text{ GeV}, \theta_{e\gamma}^* > 20^\circ)}{\Gamma(K_{e3})} &= \frac{N(K_{e3\gamma}) \text{ Acc}(K_{e3})}{N(K_{e3}) \text{ Acc}(K_{e3\gamma})} \\ &= 0.911 \pm 0.009(\text{stat})_{-0.011}^{+0.021}(\text{syst})\% \end{aligned}$$

where the samples used in the calculation are as follows

	Data	MC Gen	MC Anal	Accept
K_{e3} , no BG sub	5760880	187408000	19979000	0.106612(23)
K_{e3} , BG sub	5760140			
$K_{e3\gamma}$, (20,30), no BG sub	15575	1750190	55262	0.03158(13)
$K_{e3\gamma}$, (20,30), veto corr			55848	0.03191(13)
$K_{e3\gamma}$, (20,30), BG sub	15379			

Systematic uncertainties come from disagreements various data and MC distributions (0.004%), variation of the answer with the value of the E_γ cut ($_{-0.005}^{+0.019}\%$), the uncertainty in the K_{e3} form factor (0.007%) and the uncertainty on the veto correction (0.005%) for a total systematic uncertainty of $_{-0.010}^{+0.021}\%$. The veto correction is small, 1%, but known only to 20% of itself.

The observed branching ratio is consistent with the previous measurement by NA31[4], while considerably lower than both the CA (FFS[1] and Doncel[2]) and χ P T predictions, as shown in Figure 2.

Fearing *et al.*[1] give a phenomenological model of DE which was used to study the photon energy spectrum. They give the matrix element for $K_{e3\gamma}$ in the soft-kaon approximation as

$$\begin{aligned} T(K_{e3\gamma}) &= T_{\text{IB}} \\ &+ \frac{C}{M^2}(\epsilon \cdot l Q \cdot k - \epsilon \cdot Q l \cdot k) + \frac{D}{M^2}(\epsilon_{\mu\nu\alpha\beta} \epsilon^\mu l^\nu Q^\alpha k^\beta) \end{aligned}$$

where M is the kaon mass, ϵ is photon polarization, l is the electron-neutrino current vector, k is the photon momentum and Q is the pion momentum.

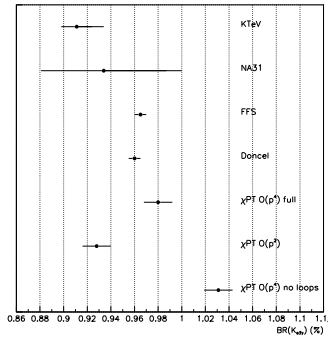


Fig. 2. A comparison of the BR result with other recent measurements and predictions.

Terms (A and B) with the kaon momentum replacing the pion momentum been left out in this approximation.

The photon spectrum was generated at a lattice of points in CD space and compared to the acceptance-corrected spectrum seen in the data. The comparisons used photons with CM energy between 25 MeV and 200 MeV and more than 5 degrees in the CM from the electron. The lattice of comparison points is not aligned with the CD axes so the χ^2 values of the comparisons were fit to fourth degree polynomials along rows, and the resulting fit parameters were themselves fit in the orthogonal direction. These fits serve as an interpolation between the measured points and allow the generation of σ contours in the CD plane.

The photon spectrum comparisons at two lattice points, the best point (left) and the IB-only point (right), are shown in Figure 3. The most significant difference between the two is a slight hardening of the photon spectrum in the 50–100 MeV region.

The 1σ and 2σ contours generated from interpolation in the CD frame are shown in Figure 4. The contours are completely contained within the simulated domain. The result is different from the IB-only spectrum at the 2σ level, which is too small to allow one to claim to have seen DE in this mode, but is enticingly similar to the difference between the branching ratio measurement and theoretical predictions.

REFERENCES

- [1] H. Fearing et al. Phys. Rev. D **2** (1970) 542.

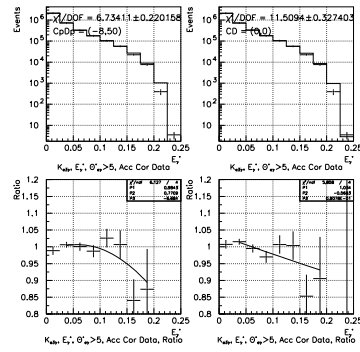


Fig. 3. Data/MC comparisons of the E_γ^* spectrum at the best $C'D'$ point and at the IB-only point.

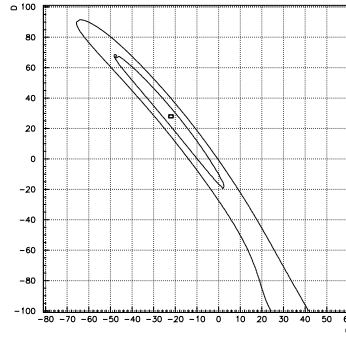


Fig. 4. The first two constant σ contours of the fit/interpolated χ^2 surface as a function of CD . The box shows the bin the lowest value.

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