KOPIO Technical Note TN098

corrected version

The tilted cube

Part 2: $K \to 2\pi^0$ *background*

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Abstract

In a previous note[1] I discussed acceptance and resolutions for signal events in the tilted cube. Here I study $K \to 2\pi^0$ background.

$K \to 2\pi^0$ even events (events in which the two photons originate from a single π^0) can only be distinguished from $K_L^0 \to \pi^0\nu\overline{\nu}$ events by the occurrence of additional photons and by the relation $E_\pi^* = m_K/2$. The level of background thus depends on the photon detection inefficiency (which in turn depends on the photon energy) and on the E_π^* resolution.

$K \to 2\pi^0$ odd events (events in which the two photons originate from different π^0's) can be distinguished from $K_L^0 \to \pi^0\nu\overline{\nu}$ events by the occurrence of additional photons and by the different distributions in E_π^*, 2γ invariant mass and energy sharing $(E_{\gamma 1}^* - E_{\gamma 2}^*)/p_{\pi^0}^* c$.

In this note I study the detector resolution and the (spectator) photon detection inefficiencies as a function of various quantities, i.e. kaon momentum, photon impact position, and missing energy.

1 Introduction

Fig. 1.1 shows distributions of E^*_π, versus photon energy sharing. In most background esti-

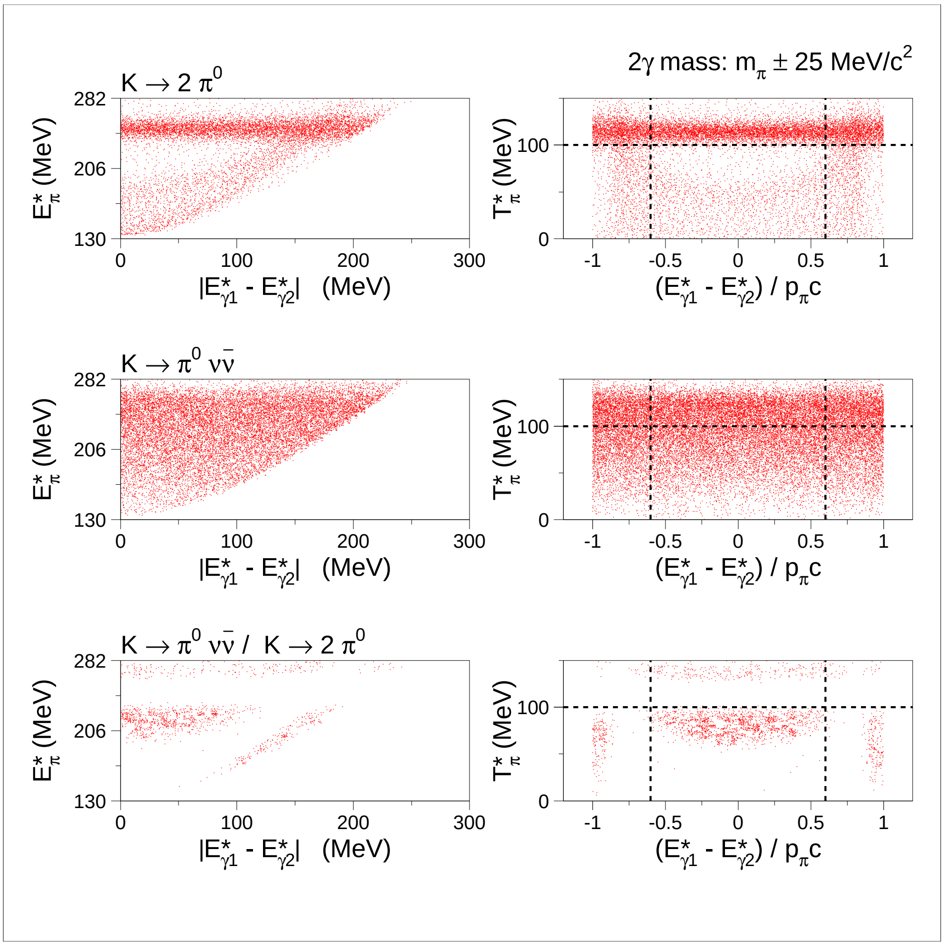

Figure 1.1: *Distributions in the kaon c.m.s. of kaon energy and photon energy sharing for both* $K \longrightarrow 2\pi^0$ *(top) and* $K^0_L \longrightarrow \pi^0\nu\overline{\nu}$ *(middle) events. Events were selected within the acceptance of the complete tilted cube[1] with* 2γ *invariant mass within 25 MeV/c*^{2} *of* m_{π^0}. *No cuts yet on the additional photons in* $K \longrightarrow 2\pi^0$. *The bottom distributions show the ratio (S/B) of the two processes. In the right distributions the* 2γ *energy difference has been normalized to its maximum value* p_π; $T \equiv E - mc^2$.

mates so far the two processes have been separated by simple linear cuts in the plane E^*_π v.s. $|E_{\gamma1} - E_{\gamma2}|$. Only the central region below $m_K/2$ was used.

An optimized analysis of the various contributions to the measured data would be based on likelihood. Question remains what quantities would be used in the likelihood calculation. Since it is unlikely that the detector resolutions are constant over phase space one probably would like to take those into account. In this note I study how the resolutions in 2γ invariant mass and E^*_π vary over phase space. It would be interesting to compare these dependences with the resolutions calculated by simple error propagation. I suggest such calculated errors for the main observables would be added to the ntuple.

I also study how the suppression factor associated with the veto on additional photons varies, in particular its variation with missing energy. Once again I had to learn that the level of $K \to 2\pi^0$ background strongly depends on the photon effi ciency in the threshold region. A threshold variation between 5 and 10 MeV (affecting the ineffi ciencies at somewhat higher energies too) corresponds to a factor two difference in $K \to 2\pi^0$ background.

2 The resolution in E_π^*

For $K \to 2\pi^0$ even events $E_\pi^* = m_K/2$ within errors. In Fig. 2.2 the mean value of $|E_\pi^* - m_K/2|$ is shown

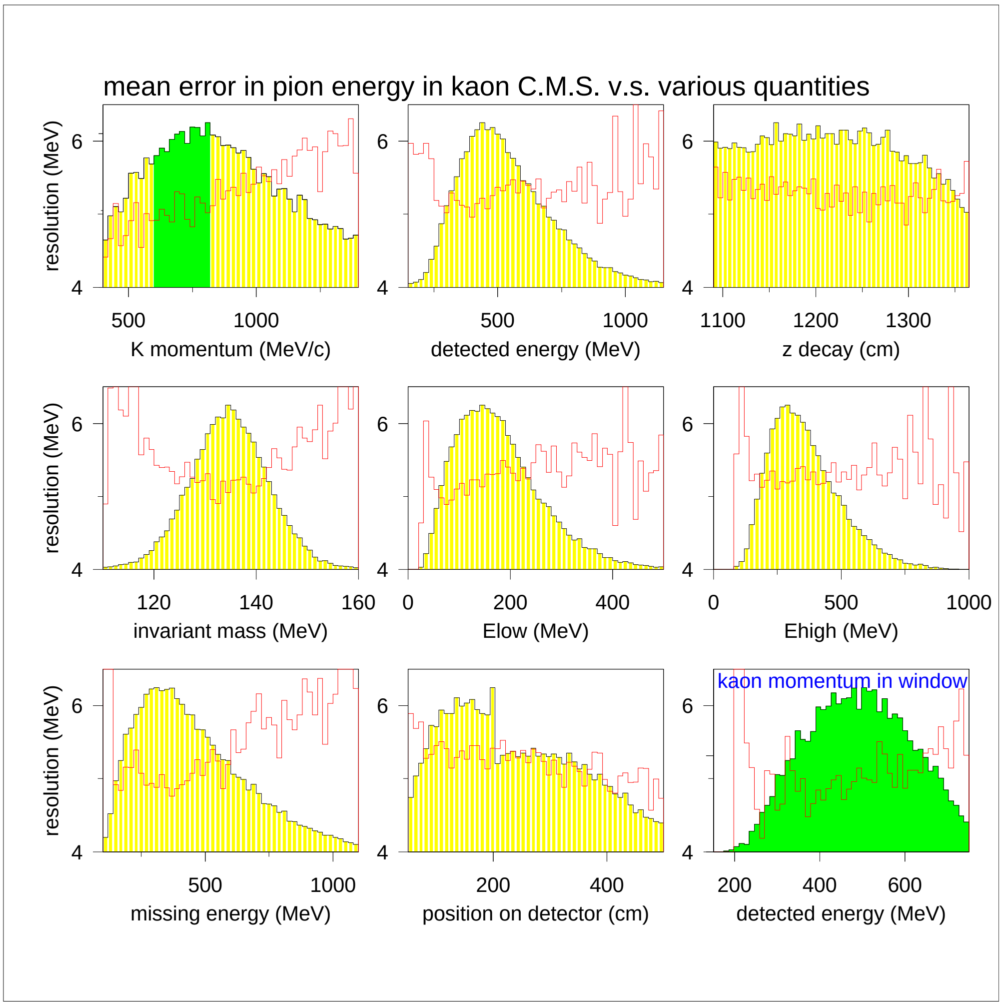

Figure 2.2: *Mean value of $|E_\pi^* - m_K/2|$ (red histograms, left scale) as a function of various quantities for $K \to 2\pi^0$ even events. The yellow histograms show the corresponding intensity distributions. In the bottom right panel events were selected from the green band on kaon momentum shown on the top left.*

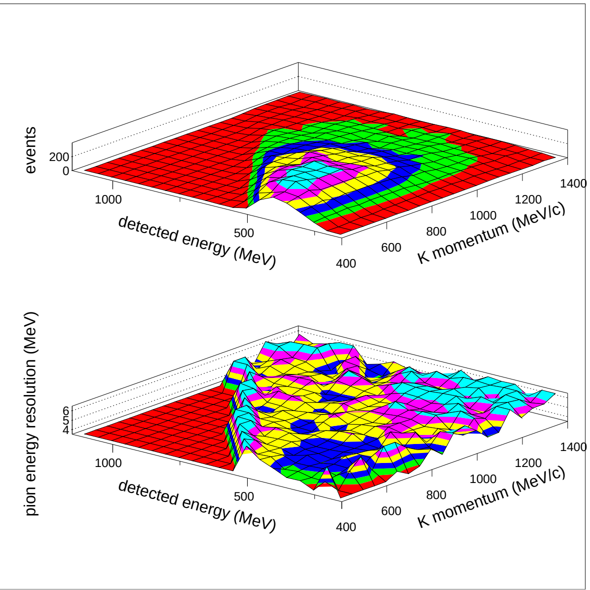

Figure 2.3: *Intensity (top) and E^*_π resolution (bottom) distributions versus kaon momentum $\times$ detected energy (total photon energy in the lab). The resolution varies between 4.5 MeV and 6.5 MeV.*

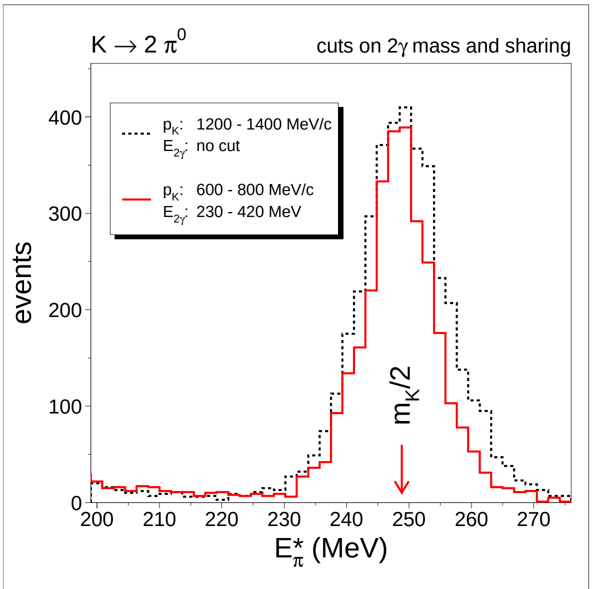

Figure 2.4: *Pion energy distribution for $K \to 2\pi^0$ (both odd and even) for two different phase space regions.*

Maybe not unexpectedly the resolution varies considerably with kaon momentum but even for a 600 - 800 MeV/c window there still remains a large variation for different event topologies.

In Fig. 2.2 one notices particularly large dependences on kaon momentum and detected energy (2γ energy in the lab). A complete picture of the variation in pion energy resolution as a function of these two quantities is shown in Fig. 2.3.

Figure 2.4 shows the E^*_π distributions for two regions with significantly different resolutions. 2γ Combinations were selected with $\pm$25 MeV/c^2 window on invariant mass and energy sharing below 60% (as indicated by the vertical dashed lines in Fig. 1.1).

As can be noticed in Fig. 2.3 the extra events accepted by the tilted cube seem to have slightly better resolution in E^*_π. One should be careful, however, in drawing conclusions on the basis of detector resolution only. As will be discussed below the $K \to 2\pi^0$ suppression factor associated with the γ veto drops one order of magnitude between p_K=400 MeV/c and p_K=1400 MeV/c which more than compensates for the worse E^*_π resolution.

3 The resolution in 2γ invariant mass

An important constraint against any background with photons not originating from a single π^0 is: $m(\gamma\gamma) = m_{\pi^0}$. As for E^*_π one may expect that the resolution in $m(\gamma\gamma)$ depends on the position in phase space. Figure 3.5 shows the resolutions for signal events with $E^*_\pi > 200$ MeV.

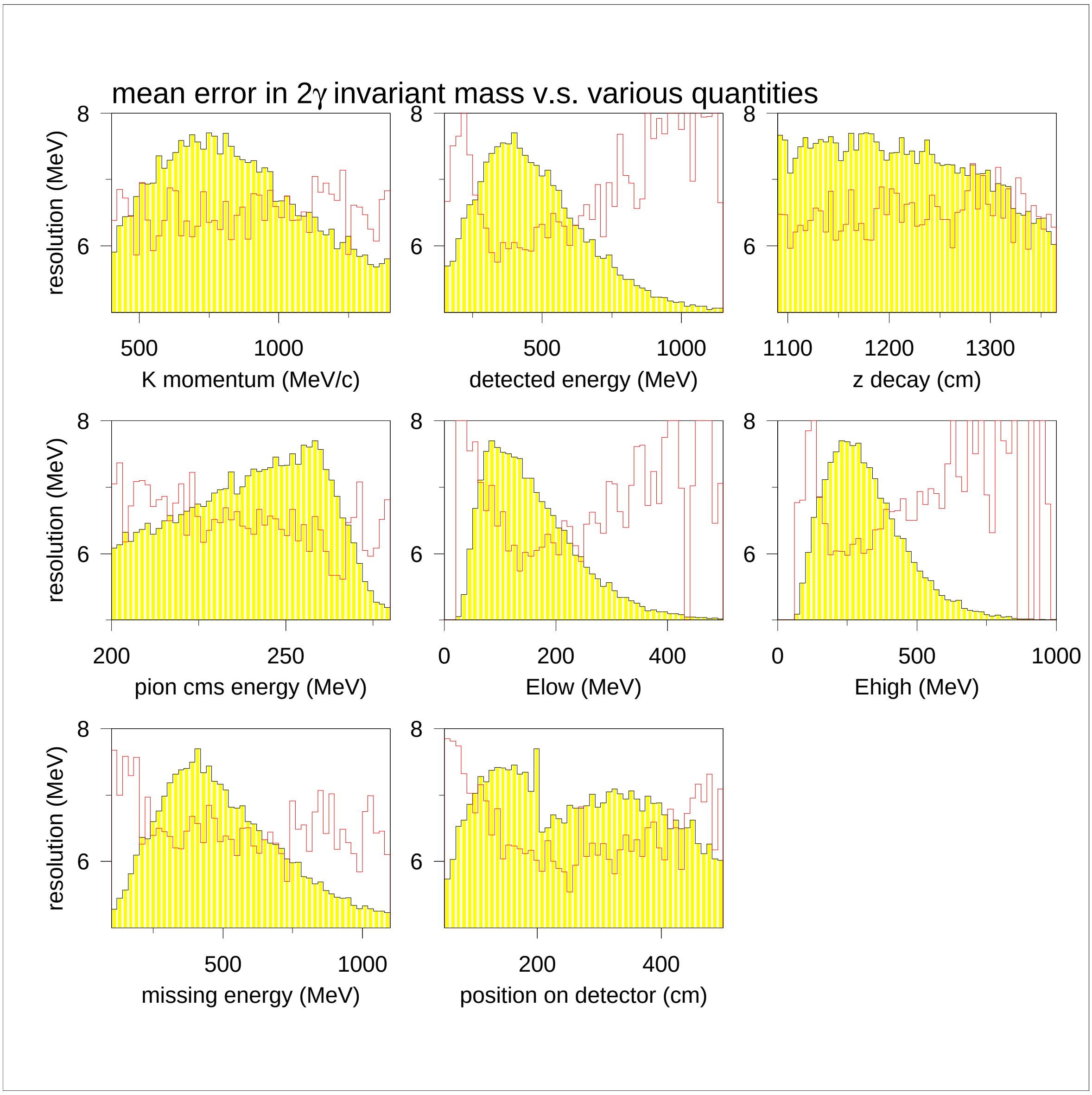

Figure 3.5: *Mean value of* $|m(\gamma\gamma) - m_{\pi^0}|$ *(red histograms, left scale) as a function of various quantities for signal events. The yellow histograms show the corresponding intensity distributions.*

This time there is little variation with kaon momentum, but a large dependence on **position on detector**. Both very forward events (presumably with small opening angle) and events with a more backward photon have worse resolutions. Again it would be useful to have an error on this quantity calculated for each individual event.

4 Photon veto efficiency and $K \to 2\pi^0$ suppression

4.1 dependence on energies of extra photons

The main measure against $K \to 2\pi^0$ background is a hermetic and efficient photon detection system. Unfortunately photon inefficiencies below 10^{-5} would be required to suppress this background below 10% of the signal on the basis of photon veto only.

The photon detection inefficiency varies as a function of energy. The exact dependence is not known but all inefficiency functions proposed so far can be described reasonably well by:

$$E_\gamma < 10 \text{ MeV}: \quad 1 - \epsilon(E_\gamma) = 1$$
$$E_\gamma > 10 \text{ MeV}: \quad 1 - \epsilon(E_\gamma) = \left(\frac{E_\gamma - 9 \text{ MeV}}{1 \text{ MeV}}\right)^{-a} ,$$

where an energy threshold of 10 MeV is assumed. For the "standard" assumption of the proposal a≈1.8.

As a result the $K \to 2\pi^0$ suppression factor is:

$$(1 - \epsilon(E_{\gamma 3}))(1 - \epsilon(E_{\gamma 4})) \approx \left(\frac{1 \text{ MeV}^2}{E_{\gamma 3} E_{\gamma 4}}\right)^a ,$$

where $\gamma 3$ and $\gamma 4$ refer to the two extra photons. Thus the energy dependence of the suppression factor depends on the geometric mean $E_{34} \equiv \sqrt{E_{\gamma 3} E_{\gamma 4}}$ of the energies of the extra photons. Note that $E_{34} > m_{\pi^0}/2$ for even 2γ combinations. It appears that this quantity has distinctly different distributions for odd and even $K \to 2\pi^0$ background (see Fig. 4.6). As

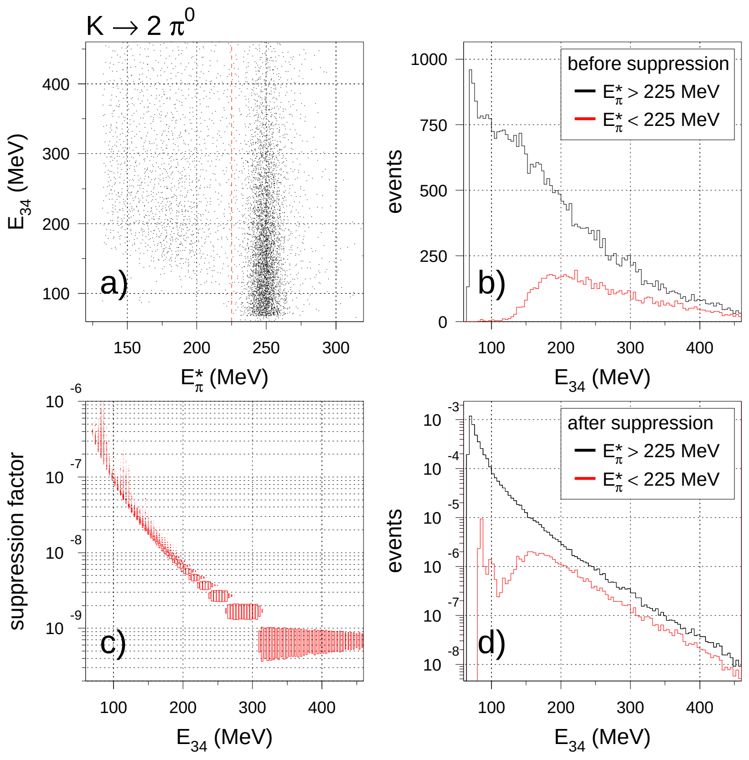

Figure 4.6:
a) geometric mean E_{34} of the energies of the two extra photons versus E^*_π
b) E_{34} distributions for two regions of E^*_π separating odd and even combinations
c) suppression factor versus E_{34}
d) as b) after suppression.

can be seen from Fig. 4.6 even $K \to 2\pi^0$ background peaks at the E_{34} threshold where the suppression factor is $O(10^{-6})$. This region in particular would benefi t enormously from a lower photon energy threshold. Odd background has typically twice higher values for E_{34} which results in a suppression factor below $O(10^{-8})$. Unfortunately also in the low E^*_π region there are few events with E_{34} values below 100 MeV. As can be seen from Fig. 4.6d these events get strongly enhanced by the poor suppression factor.
It would be nice to be able to request a threshold on E_{34} which of course is not possible for unobserved photons. There is, however, another observable that strongly correlates with E_{34} and is always available: **reconstructed missing energy**.

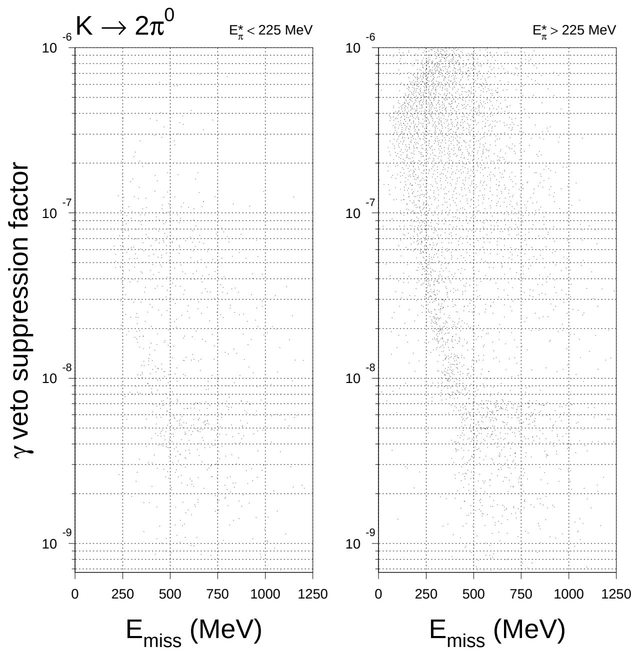

Figure 4.7: *$K \to 2\pi^0$ suppression factor obtained with the γ veto for two different regions of E^*_π separating odd and even 2γ combinations.*

4.2 dependence on reconstructed missing energy

Figure 4.7 shows the $K \to 2\pi^0$ suppression factor versus missing energy for two regions of T^*_π. It appears that for equal missing energy odd background is suppressed ten times better than even background.
Figure 4.8 shows signal and $K \to 2\pi^0$ background with/without γ veto in the *missing energy* $\times$ T^*_π plane.
The plot on the bottom left shows contours of equal S/B ratio. The event selection illustrated on the bottom center and right follows one such contour. The signal region has been cut at T^*_π ≈60 MeV to suppress $K \to \pi^+\pi^-\pi^0$ background. About 24% of the signal events are accepted.

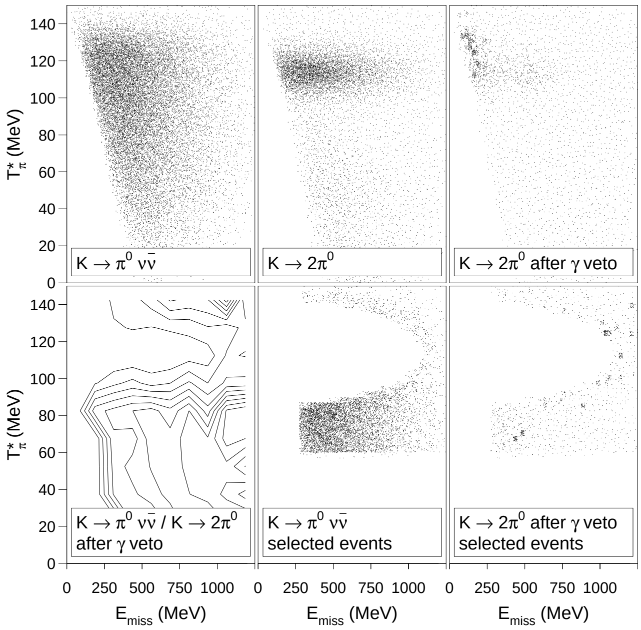

Figure 4.8: *Signal and $K \to 2\pi^0$ background in the missing energy $\times$ T^*_π plane. Signal regions are defined along a contour of constant S/B ratio.*

Figure 4.9 shows distributions of **position on detector**[1] for signal and $K \rightarrow 2\pi^0$ background events for two assumptions for the threshold on the photon veto signals. As discussed above already it appears crucial to capture photon veto signals down to 5 MeV. For that threshold S/B ratios of 4-5 can be expected over the full acceptance.

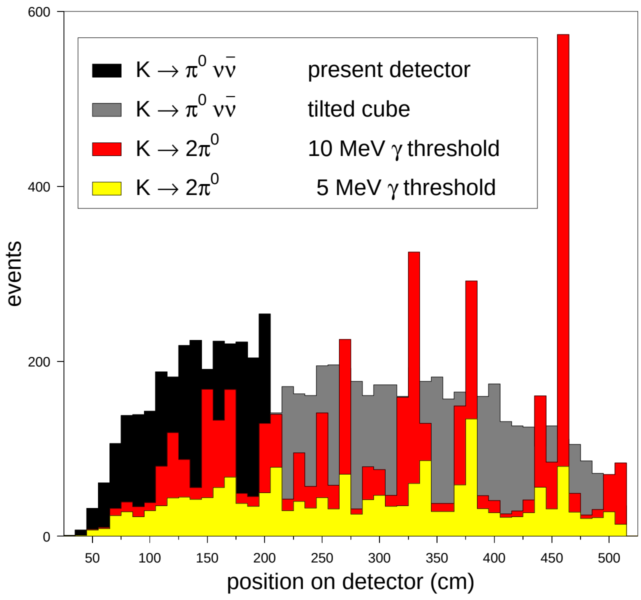

Figure 4.9: *Distributions of position on detector[1].*

5 Conclusions:

- Both detector resolution and $K \rightarrow 2\pi^0$ background do not change significantly when increasing the KOPIO acceptance to the one of the tilted cube.
- Using a correlated cut on E^*_π and missing energy $K \rightarrow 2\pi^0$ background can be reduced below 25% at the cost of "only" a factor 4 loss in sensitivity if a photon veto threshold around 5 MeV can be reached.

References:

[1] TN097 The tilted cube, *Part 1: acceptance and background considerations*, A. van der Schaaf, 30 June 2004