Remarks about Normalization and Matching, Part I

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December 4, 1995

Abstract

We present our current understanding of normalization effects caused by different trigger decisions and give recipes to correct for such effects. We also show, what are the remaining problems and what are the limitations of using the results obtained with $\pi^+\pi^-$ decays for other final states. Most of the effects are very small and it is difficult to predict the consequence on different measurements without going through a detailed analysis. Since the trigger decisions had been successively reduced during the CPLEAR data taking, one can study the effect of some of the trigger decisions by using unbiased data. Part I will deal with the effects of dE/dx, kaon-logic and the z-correction. In part II, we will present the effects of track counting and charge conservation based on the analysis of P28 and Monte Carlo data.

1 Overview of different trigger conditions

We describe shortly the trigger conditions used during the major part of data taking in each period. Common to all periodes is the requirement to have at least one kaon candidate, $S\overline{C}S$, p_t cut, primary and valid track and another primary valid track with opposite charge. In addition we demand:

before Period 21 T223 or T423, two separate triggers, accepting events with two primary and two secondary tracks or events with 4 primary tracks. Charge conservation of the whole event, $\sum Q = 0$.

Period 21-23 T605172223 and T607163323, full trigger, no two kaon candidates with same charge in REGISTER, wrong LUT for z correction, AND-logic in HWP2. After P22, accept in addition events with four tracks and three primary tracks or events with three tracks and two primary tracks. $\sum Q = 0$ only for events with four primary tracks.

Period 24 TX05163323, no 2 kaon candidates with same charge in REGISTER, $\sum Q = 0$ for events with four primary tracks, wrong LUT for z correction, AND-logic in HWP2.

Period P25 T607163323, $\geq$ 1 kaon candidate in REGISTER, $\sum Q = 0$ for events with four primary tracks, wrong LUT for z correction, OR-logic in HWP2 and open dE/dx cut for pions.

Period P26 T507163323, $\geq$ 1 kaon candidate in REGISTER, $\sum Q = 0$ for events with four primary tracks, no z correction, OR-logic in HWP2 and open dE/dx cut for pions.

Period P27 T507163323, $\geq$ 1 kaon candidate in REGISTER, $\sum Q = 0$ for events with four primary tracks, no z correction, OR-logic in HWP2, open dE/dx cut for pions and only cut on kaon dE/dx for the first kaon candidate.

Period P28 and P29 T507110026, two clusters in PC0, $\geq$ 1 kaon candidate in REGISTER, at least two primary tracks with opposite charge, no z correction, OR-logic in HWP2, open dE/dx cut for pions and only cut on kaon dE/dx for the first kaon candidate.

The identification of kaons in HWP2 is based, in addition to dE/dx, also on Čherenkov information but only for the first kaon. The ToF information is always used in an OR-logic. Open dE/dx cut for pions refers to the maximum range possible in HWP2 which is from zero to approximately 25 times the energy of a minimum ionizing particle.

2 Normalization

Normalization is the ratio of the detection efficiencies for events with original $\overline{\mathrm{K}}^0$ and K^0. As long as this ratio does not directly depend on the decay products of the neutral kaon, normalization can be separated from CP violation. The normalization ξ depends on the momenta of the primary particles ($\mathrm{K}^\pm$ and $\pi^\mp$). When looking at the ratio of $\overline{\mathrm{K}}^0$ over K^0 events as function of lifetime one usually integrates over all occuring primary and secondary momenta and decay radii, with the constraints $\tau = M_{\mathrm{K}^0}/|\vec{P}_{\mathrm{K}^\pm} + \vec{P}_{\pi^\mp}| \cdot r = M_{\mathrm{K}^0}/|\vec{p}_{\pi^-} + \vec{p}_{\pi^+}| \cdot r = \mathrm{const.}$:

$$\begin{aligned} R_{\mathrm{obs.}}(\tau) &= \frac{\int_C \overline{f}(\vec{P}_{\mathrm{K}^+}, \vec{P}_{\pi^-}) \times \overline{g}(\vec{p}_{\pi^-}, \vec{p}_{\pi^+}, r) d^6P\, d^6p\, dr \times n_{\overline{\mathrm{K}}^0}(\tau)}{\int_C f(\vec{P}_{\mathrm{K}^-}, \vec{P}_{\pi^+}) \times g(\vec{p}_{\pi^+}, \vec{p}_{\pi^-}, r) d^6P\, d^6p\, dr \times n_{\mathrm{K}^0}(\tau)} \\ &= \xi(\tau) \times R_{\mathrm{CP}} \end{aligned} \tag{1}$$

where $f(\vec{P}_{\mathrm{K}^-}, \vec{P}_{\pi^+})$ is the reconstruction efficiency of a specific primary momenta configuration (independent of decay time and decay radius), $g(\vec{p}_{\pi^+}, \vec{p}_{\pi^-}, r)$ is the neutral kaon decay reconstruction efficiency and n_{K^0} is the expected rate of K^0 decays. For the decay $\mathrm{K}^0 \to \pi^+\pi^-$, we have: $\overline{g}(\vec{p}_{\pi^-}, \vec{p}_{\pi^+}, r) = g(\vec{p}_{\pi^+}, \vec{p}_{\pi^-}, r)$, since the π^+ and π^- momentum distributions are the same for K^0 or $\overline{\mathrm{K}}^0$ for any K^0 momentum. This is special to the 2π decay mode and not valid for the semileptonic and $\pi^+\pi^-\pi^0$ decay.

Due to different strong interactions of pions and kaons of positive and negative charge with the detector material (fig. 1, 3, 6), we have:

$$f(\vec{P}_{\mathrm{K}^-}, \vec{P}_{\pi^+}) \neq \overline{f}(\vec{P}_{\mathrm{K}^+}, \vec{P}_{\pi^-})$$

Due to geometric imperfections, the trigger has also different efficiencies for finding left and right curvature tracks. This inequality is balanced by changing the magnetic field frequently (fig. 1).

The average normalization ξ could depend on the lifetime τ, if the reconstruction efficiency for the decay vertex $g(\vec{p}_{\pi^+}, \vec{p}_{\pi^-}, r)$ changes with radius. Which is for example always the case for a detector with finite decay volume. This has the consequence, that that for a given lifetime τ not all primary momentum configurations lead to a decay vertex which can be reconstructed inside the detector and therefore the average normalization changes with lifetime. By measuring experimentally the function:

$$\mathrm{LUT}(\vec{P}_{\mathrm{K}^\pm}, \vec{p}_{\pi^\mp}) = \frac{\overline{f}(\vec{P}_{\mathrm{K}^+}, \vec{P}_{\pi^-})}{f(\vec{P}_{\mathrm{K}^-}, \vec{P}_{\pi^+})}, \tag{2}$$

we are able to weight the events $n_{\mathrm{K}^0}(\tau)$ properly to obtain the pure CP-effect:

$$\begin{aligned} R_{\mathrm{CP}}(\tau) &= \frac{\int_C \overline{f}(\vec{P}_{\mathrm{K}^+}, \vec{P}_{\pi^-}) \times \overline{g}(\vec{p}_{\pi^-}, \vec{p}_{\pi^+}, r) d^6P\, d^6p\, dr \times n_{\overline{\mathrm{K}}^0}(\tau)}{\int_C f(\vec{P}_{\mathrm{K}^-}, \vec{P}_{\pi^+}) \times \mathrm{LUT}(\vec{P}_{\mathrm{K}^\pm}, \vec{p}_{\pi^\mp}) \times g(\vec{p}_{\pi^+}, \vec{p}_{\pi^-}, r) d^6P\, d^6p\, dr \times n_{\mathrm{K}^0}(\tau)} \\ &= \frac{\int_C \overline{f}(\vec{P}_{\mathrm{K}^+}, \vec{P}_{\pi^-}) \times \overline{g}(\vec{p}_{\pi^-}, \vec{p}_{\pi^+}, r) d^6P\, d^6p\, dr \times n_{\overline{\mathrm{K}}^0}(\tau)}{\int_C \overline{f}(\vec{P}_{\mathrm{K}^+}, \vec{P}_{\pi^-}) \times g(\vec{p}_{\pi^+}, \vec{p}_{\pi^-}, r) d^6P\, d^6p\, dr \times n_{\mathrm{K}^0}(\tau)} \\ &= \frac{n_{\overline{\mathrm{K}}^0}(\tau)}{n_{\mathrm{K}^0}(\tau)} \end{aligned}$$

The function $\mathrm{LUT}(\vec{P}_{\mathrm{K}^{\pm}}, \vec{p}_{\pi^{\mp}})$ can either be determined simultaneously with the CP violation parameters, or in an iterative procedure by first fixing the CP violation parameters to some initial values.

This procedure assumes that there is no direct dependence of the normalization on the secondary decay products. The difference in φ_{+-} that we observe, when analysing the data for the two magnetic fields separately, might be the result of such a correlation. However, by analysing the data symmetrically in curvature, the difference is very much reduced. This will be discussed in part II of our remarks on normalization effects.

3 Matching

Matching is the selection of those events, where the primary tracks, defined at the end of the analysis, passed through all trigger levels. This is verified by simulating all the trigger levels. A correct matching is essential for selecting a sample of events which is free of any bias of the K^0 decay products. Two trigger conditions used in some periods prohibit to obtain, with the matching alone, a bias free sample. These are the AND-logic in HWP2 (section 5) and charge conservation for four primary events (part II of normalization effects).

4 Wrong z correction

Although the use of wrong LUT for an online z correction of the twist of the driftchambers caused strong variation of the normalization as function of z, it didn't affected the CP asymmetry for the $\pi^+\pi^-$ final state (see figure 2).

5 Effect of dE/dx cut with AND-logic

In P24, events only passed if both pions with opposite charge to the kaon satisfied the dE/dx cut of HWP2 (AND-logic). In addition, the efficiency for a pion to pass the dE/dx cut of HWP2 is different for π^- and π^+ (fig. 3). The AND-logic couples the detection of decay products of a neutral kaon to the primary particles and lead to a difference of the normalization as function of lifetime and radius. Fig. 4 shows how the normalization changes when switching on the AND-logic of the trigger. The step in the normalization for decays after PC2 is explained by by the fact, that after PC2, the trigger can only see the 2 primary tracks and therefore cannot demand that the secondary pion passes the dE/dx cut in HWP2.

<u>Solution:</u> The obvious solution was to change the trigger decision for later data taking ($\geq$ P25). By using the OR-logic, i.e. the event is accepted if one of the pions with opposite charge of the kaon passes the dE/dx cut, one accepts

more events and could select offline those events where the true primary pion passes the dE/dx cut. These events are independent of wether the secondary pion passes the dE/dx cut or not.

In order to use the data of P24, a similar dE/dx cut as done in HWP2 was applied to all pions regardless of their charge. By doing this, the step in the normalization observed before disappeared. A detailed analysis of P25 data with the same conditions as in P24 but with the OR-logic shows that by simulating the AND-logic, we observe a change of normalisation of $\approx 1.5\%$ (fig. 4) inside PC2. By applying in addition the standard procedure of removing all events where any pion does not pass the dE/dx cut, we come back to the original normalisation within $(2 \pm 6) \times 10^{-4}$ (fig. 5).

One important remark: There is no reason to reject events with decays outside PC2, where a pion does not pass the dE/dx cut. Although this cut does not alter the normalization within $\pm 3 \times 10^{-3}$, it removes for no good reason 30% of events with decays outside PC2 !

Applying a dE/dx cut on all pions symmetrizes the data for all lifetimes as long as the momentum distribution of the secondary pions is not different for K^0 and $\overline{K}^0$. This is the case for the 2π final state, but not necessarily for the 3π and semileptonic final state specially when looking at different regions of the phase-space.

A complication of this procedure, is that only the pion dE/dx cut is symmetrized up to now, but it is not checked if the pion could have been misidentified as a kaon and therefore be passed through the kaon dE/dx cut. In P24, no events with a second kaon candidate with the same charge as the first had been accepted. Only those events passed, where a misidentified pion with the opposite charge of the kaon passed the HWP2 accidentally. This should be a small fraction, but the correct procedure would be to remove all events with false kaon candidates. Normalization effects caused by removing events with false kaons correlated to the charge of the first kaon are demonstrated in fig. 10 and 11.

The limit of this symmetrization might be the fact that for decays outside PC2, no second kaon candidate with opposite charge of the first kaon is possible. Therefore, the normalization inside and outside of PC2 can only be the same if the momentum distribution of secondary pions is the same for K^0 and $\overline{K}^0$. Otherwise the normalization will change after PC2.

6 The double KAON-logic

A general problem for the trigger is the misidentification of a pion as a kaon candidate. A kaon candidate is a valid primary track with $S\overline{C}S$ which passed the p_t cut. The probability to misidentify a pion as a kaon is shown in figure 6 for pions of different charge as function of their momentum. Removing the events where the primary pion was seen as a kaon candidate in the trigger leads to an acceptance shown in fig. 7.

In all periods, if the first kaon candidate is a misidentified pion, the event will be removed in HWP2 by the dE/dx cut on kaons. The probability for such a misidentification is slightly different for π^- and π^+. Fortunately this should not introduce any bias for the 2π decay mode:

- If the misidentified kaon was in fact the true primary pion, the difference of misidentifying π^- and π^+ contributes to the overall normalization defined by the primary particles (fig. 8)
- If the misidentified kaon was one of the decay products, no change of the normalization is expected, since there is no difference for π^- and π^+ coming from K^0 or $\overline{K}^0$ in the 2π decay mode (fig. 9).

Similar tests should be done for the semileptonic and 3π final state, to learn about the possible bias always present in the data due to removing events where a misidentified pion was found before the true kaon.

In P24, all events with a misidentified pion should have been removed. Events with like sign kaons had been not allowed by the REGISTER and events with unlike sign kaons had been removed in HWP2.

After P24, events had been removed by the trigger or by the matching were the real primary pion had been misidentified as a kaon. Events with misidentified secondary pions as kaons were kept as long as the real kaon was found first. Removing events with misidentified secondary pions depending on the relative charge of the first and second kaon candidate[i], introduces variation of the normalization with the decay radius and lifetime (fig. 10 and fig. 11).

7 Conclusion

At the end of the analysis, when the primary tracks are well defined, the matching should be applied to ensure that the event had been accepted without a bias from the decay products. Assuming that the matching works perfect, no further cuts (removing false kaons) are required after P24. Special care about residual effects have to be taken for the semileptonic and 3π final state. Concerning the 2π analysis: The wrong LUT for the z-correction had no impact on the physics results, the step of normalization inside PC2 due to the AND-logic is corrected offline to a precision better than 6×10^{-4}, no effect of the kaon-logic is expected.

[i] As done for some time in the official matching procedure. However this procedure was not used for the $\pi^+\pi^-$ analysis

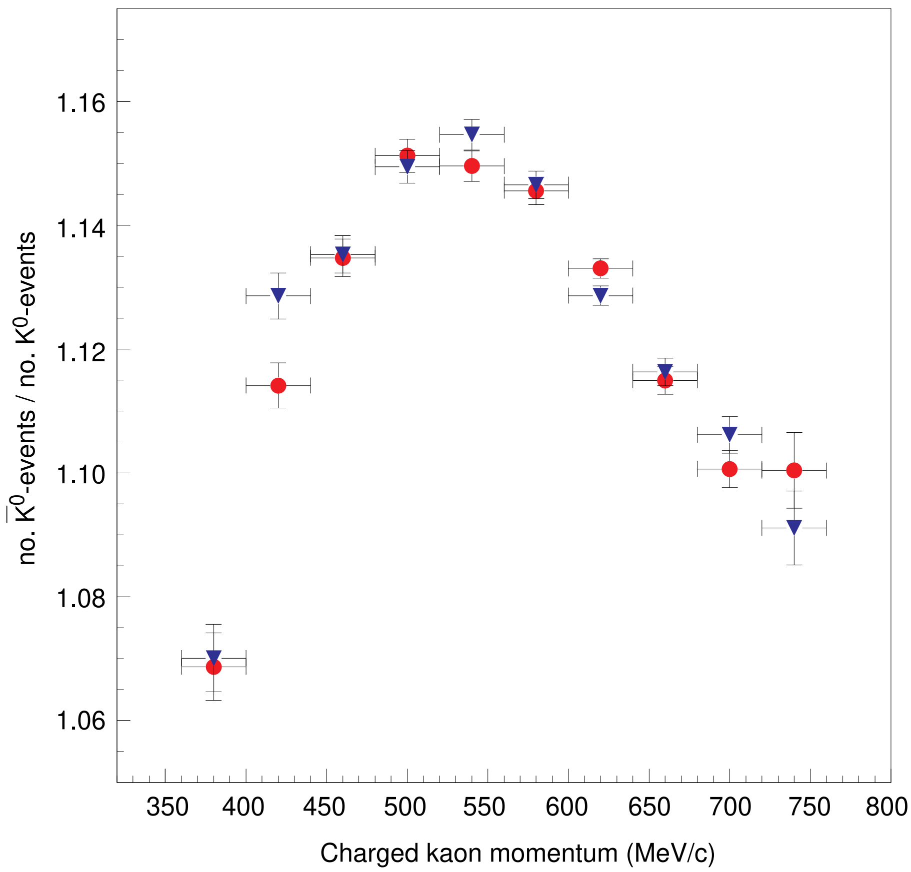

Figure 1: Normalization of events with the same curvature as function of the charged kaon momentum

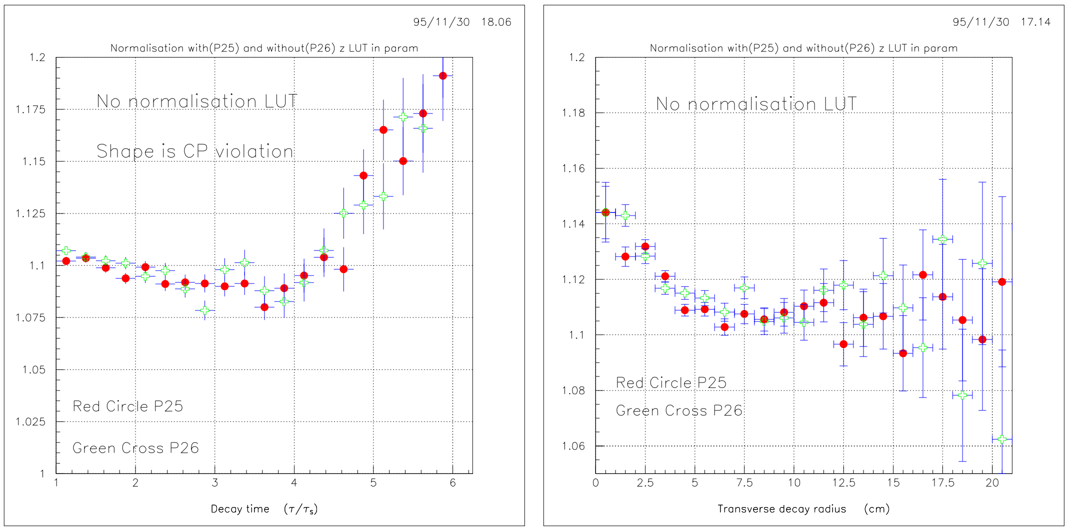

Figure 2: Normalization as function of radius and lifetime in P25 with wrong LUT for z correction and in P26 without z correction. The distribution as function of radius had been corrected for CP. The shape in lifetime is due to the CP-effect and the shape in radius is a reflection of the 1 τ_S lifetime cut, which changes the average normalisation as function of radius.

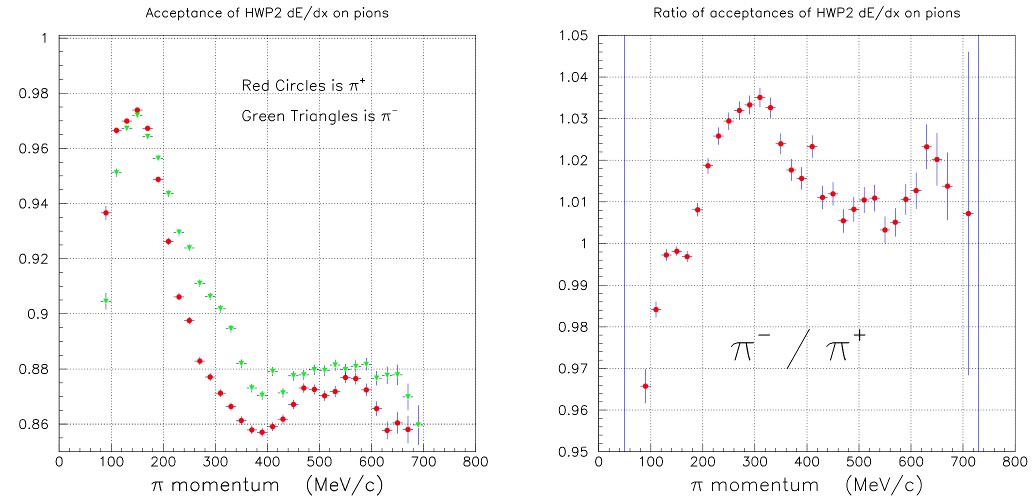

Figure 3: Efficiency for pions to pass the HWP2 dE/dx cut on pions. The shape is given by the boundary conditions of HWP2 for the expected dE/dx of a pion. The difference between π^- and π^+ is due to the Δ^{++} resonance.

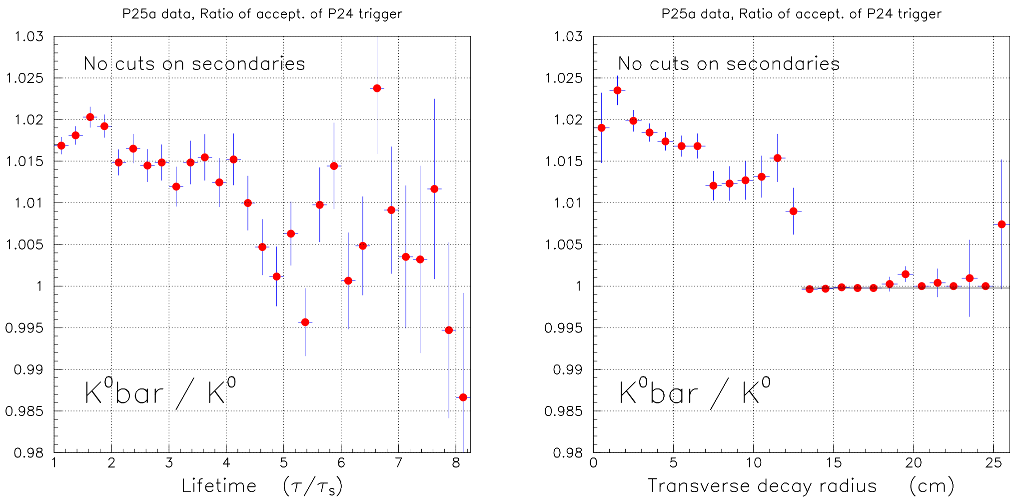

Figure 4: Relative change of normalization for events, when switching on the AND-logic for dE/dx in HWP2.

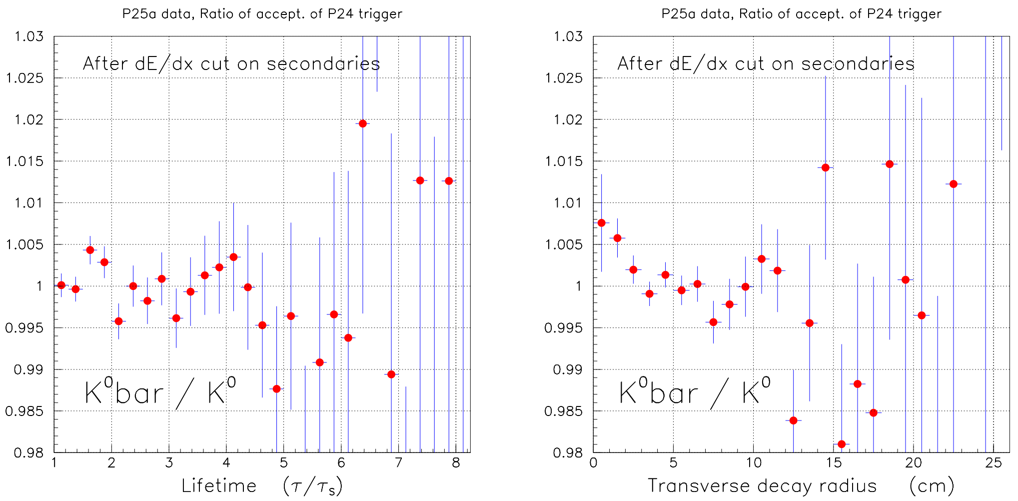

Figure 5: Relative change of normalization for events, when switching on the AND-logic for dE/dx in HWP2 and using the offline correction procedure.

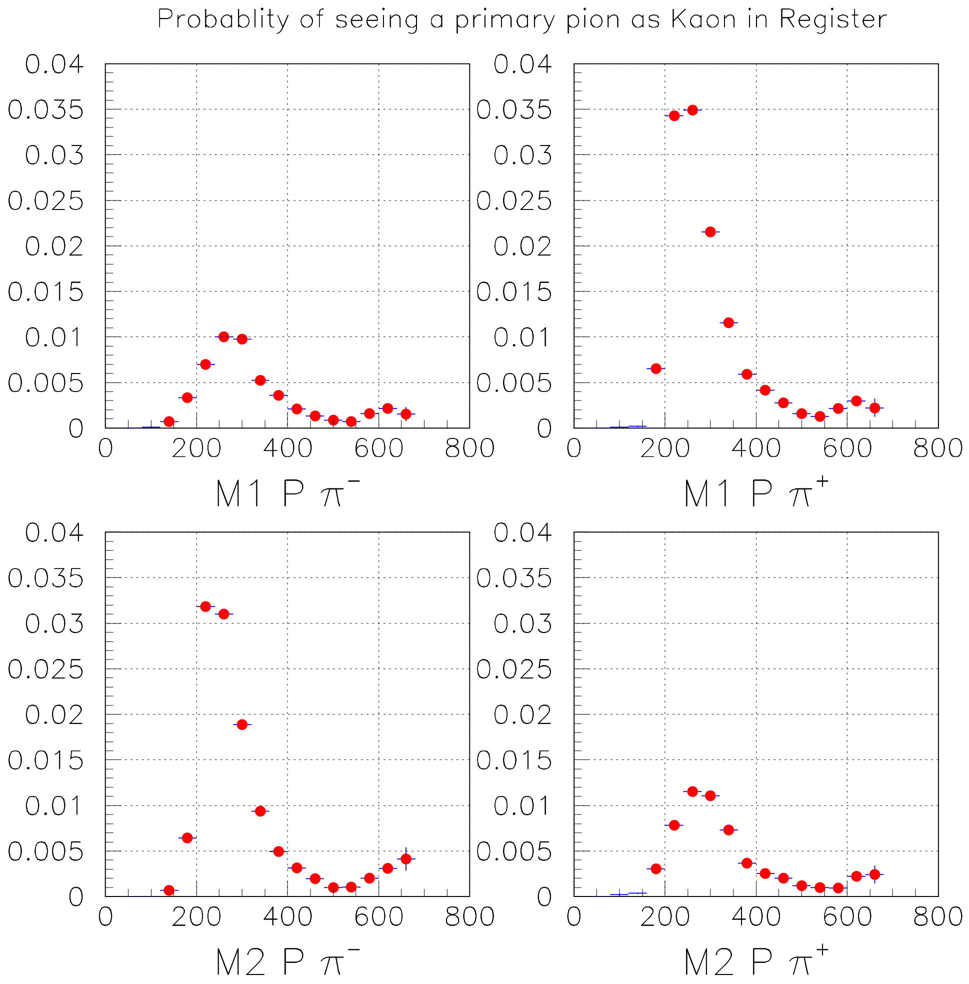

Figure 6: Probability for misidentifying a pion as a kaon as function of the pion momentum. There is a clear difference for positive and negative curvature to pass the p_t cut.

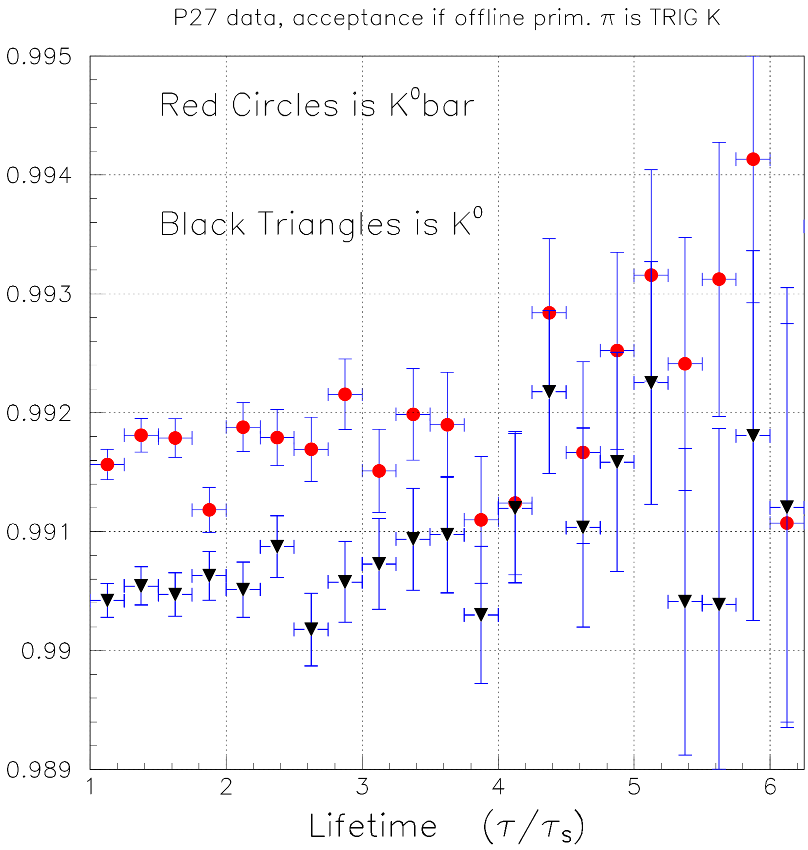

Figure 7: Relative change of acceptance for K^0 and $\overline{K}^0$ separately if events are removed where the true primary pion was seen as a kaon.

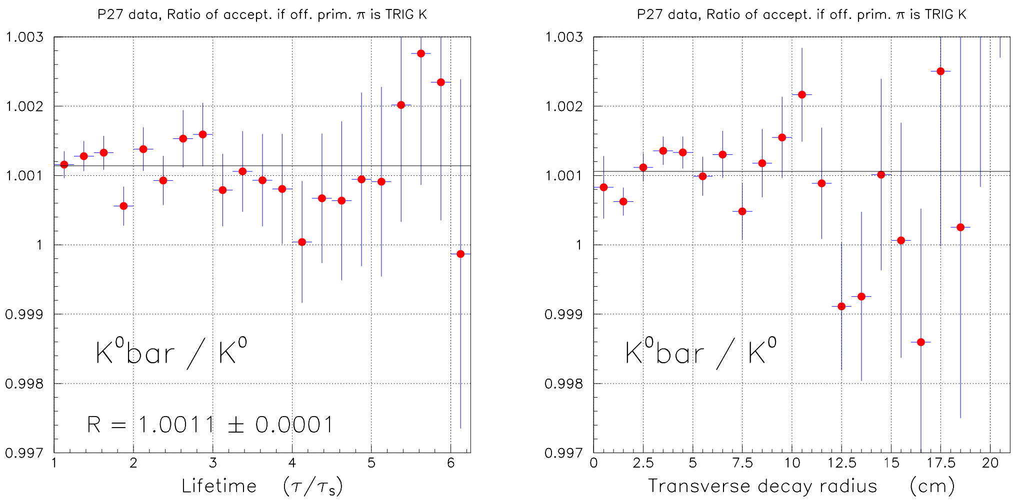

Figure 8: Relative change of normalization if events are removed where the true primary pion was seen as a kaon.

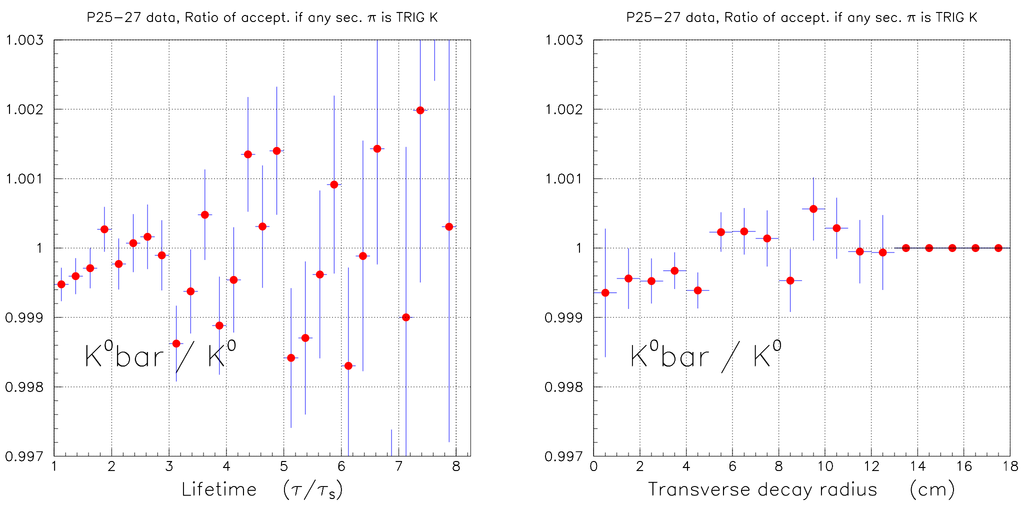

Figure 9: Relative change of normalization if events are removed where a secondary pion was seen as a kaon.

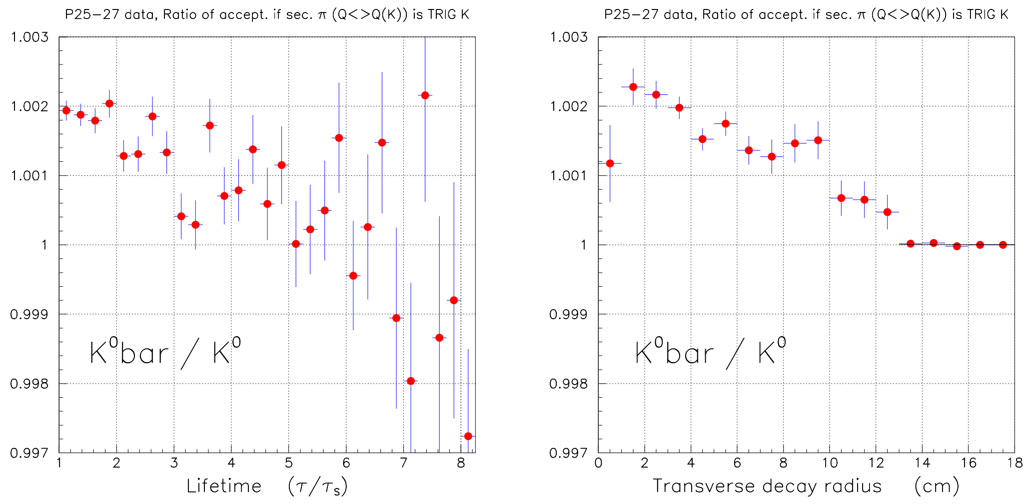

Figure 10: Relative change of normalization for events, where one of the decay particles was seen as a kaon and had the opposite charge as the primary kaon.

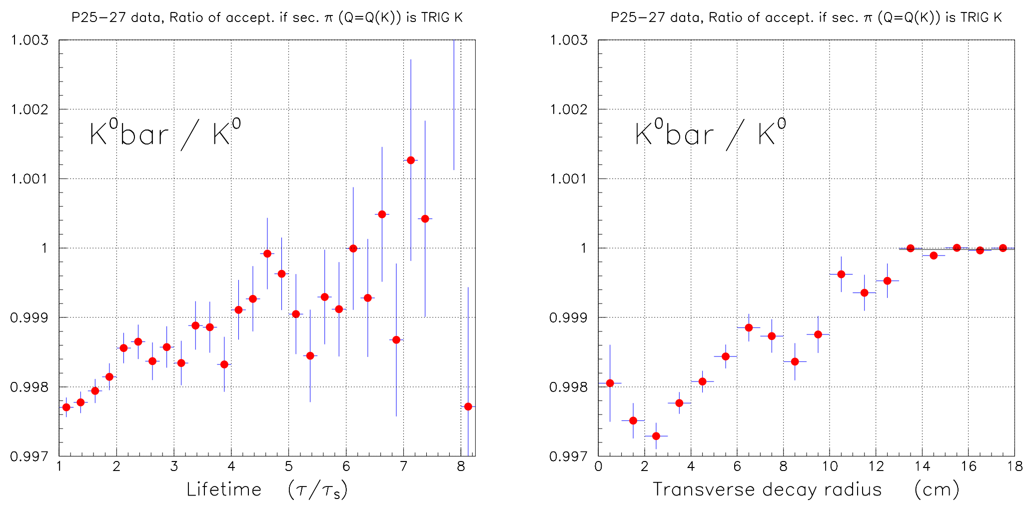

Figure 11: Relative change of normalization for events, where one of the decay particles was seen as a kaon and had the same charge as the primary kaon.