Dependence of normalization on constrained fits probability : study on $\pi^+\pi^-$ decays PART I

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A comparison of physics results from P25 to P27 $\pi^+\pi^-$ data with different probability cuts has revealed a significant sensitivity. This is a consequence of the dependence of normalization on constrained fit probability cuts and particularly on the reconstruction quality of the primary $K^\pm\pi^\mp$ pair. The results of this study are presented and the implications for the normalization correction method used currently for all charged final states are discussed.

1 Introduction

For most of the CPLEAR measurements which are extracted from time dependent decay rate asymmetries any apparent variation of the normalization with lifetime would result in a bias. The method used to correct for this dependence is to make LUTs from early decay time $\pi^+\pi^-$ events and then use them on all data ($\pi^+\pi^-$, semileptonics, $\pi^+\pi^-\pi^0$) and all lifetimes. This method is based on the assumption that the relative tagging efficiency ξ for K^0 and $\overline{K^0}$ events depends only on the primary $K^\pm\pi^\mp$ pair kinematics; the tagging efficiency for the decay products is either assumed to be symmetric ($\pi^+\pi^-$, $\pi^+\pi^-\pi^0$) or is parametrized separatelly (η of semileptonics) assuming that ξ and η are independent.

It has been established that at least before 1995 the trigger conditions introduced some correlations between the primary and secondary track pairs which violated the above assumptions in the samples of M1 and M2 separatelly, and up to P24 also for the sum of M1+M2. Special cuts are used in order to remove such dependencies. The principles and main implementation details of all the above can be found in [1], [2], [3] and in the presentations of the normalization session of the CPLEAR collaboration meeting of February 7 1996.

In this report another source of primary–secondary correlation is presented : constrained fits using both primary and secondary particles. If the track fit resolution was the same for $K^-\pi^+$ and $K^+\pi^-$ pairs, then ξ would indeed be independent of the type of fit and probability cut used in event selection. However this is not the case; events in the same bins of primary kinematics have different ξ depending on the probability of the respective events in the constrained fits. This poses the following problems :

- One is not free to use any radius– or lifetime–dependent cut choosen only on the basis of signal acceptance and background rejection
- Use of the LUTs and the overall normalization factors from $\pi^+\pi^-$ data on other final states (selected with different constrained fits) is not expected to work well
- Use of anti–fits in a particular region of radius or lifetime for background rejection could lead to a different normalization in this region compared to the rest of the data of the same final state

The present study has been done on $\pi^+\pi^-$ data; the discrepancy between results obtained with different variable cuts on the 9c fit probability is presented as a demonstration of the first of the points mentioned above. The results obtained with different constant cuts, more consistent with each other, are also shown. Then the dependence of ξ on the probability is demonstrated and the dependence on primary kinematical variables is shown. Note that the M1/M2 total event ratio is also modified by varying the cut. The effect is localised in the reconstruction of the primary particle tracks and is shown to be a function of the 1c fit probability. More detailed studies are needed to reach final conclusions; an outline closes this report.

2 $\pi^+\pi^-$ event selection

The selection of $\pi^+\pi^-$ events, based on quality cuts and constrained fits, is mainly included in the (common for everybody in the $\pi^+\pi^-$ group) MINI and MICRO production software. All events passing these cuts and having a probability of more than 5% in any of the 5c fits (greek or saclay) are written on micro. This common selection is described in [4]. In the same report one can find a comparison of 5c and 9c acceptances and resolutions. The main differences are the higher signal/background ratio obtained by the 9c fit and the worse resolution of the 5c, mainly due to tails. The latter was extensively studied by M. Carroll on high statistics data and Monte Carlo, reaching the conclusion that 9c results are more stable and easy to describe due to this difference in tails. Following this study, which was presented in the $\pi^+\pi^-$ session of the collaboration meeting on February 7 1996, it was decided to procceede using only the 9c fit for event selection and resolution improvement.

Thus when reading the micro events, all events having a probability of more than 5% on the 9c are accepted. On these the following cuts are currently imposed :

- trigger matching using the TRIG routine [5]
- a cut in the transverse opening angle of the secondaries ($-0.99 < cos(\theta) < 0.98$)
- events under $1\tau_s$ are either rejected or not used in the subsequent analysis (available anyway only on P27 production)
- A higher probability cut for events at high radius/high lifetime in order to achieve a low and as much as possible flat (relative to the $\pi^+\pi^-$) background acceptance in lifetime

A small number of additional cuts, affecting a very small percentage of events without bringing a significant improvement in bgr/signal ratio or resolution have been in use up to now, but most of them will be removed in the final common selection which is under preparation.

3 The different probability cuts

As the decay vertex moves away from the center of the detector in the transverse plane less points are available from the PC and DC chambers for the reconstruction of the decay particles. This results in larger errors from the track fit and consequently to worse signal/background selectivity of the constrained fits for any given probability cut. This is demonstrated in figures 1 and 2, where the MC acceptance for semileptonics, $\pi^+\pi^-$ and their ratio versus radius and lifetime are shown for a flat probability cut of 5%. Flat probability cuts at 25% and 40% give similar shapes with lower bgr/signal levels, as expected.

To improve the relative background level and shape, a lifetime dependent cut has been defined some years ago by C. Yeche. It has the form :

$$P_{9c} > \sqrt[4]{\frac{\tau - 6}{150}}$$

The improvement in the acceptances versus radius and lifetime is shown in figures 3 and 4. Comparing figures 2 and 4 we observe a relative reduction of background at higher lifetimes but the ratio bgr/signal has a peak in the region 4–6τ_s. This cut is subsequently refered to as the "lft 6" cut.

In an attempt to remove this peak, one can modify the cut as follows :

$$P_{9c} > \sqrt[4]{\frac{\tau - 4}{180}}$$

The improvement in the acceptances versus radius and lifetime is shown in figures 5 and 6. This cut is subsequently refered to as the "lft 4" cut. The form of the two lifetime dependent cuts is shown in figure 9.

Another way to achieve comparable results is the radius dependent cut used by C. Touramanis. This is a cut of 40% outside PC2 (decay transverse radius $\geq 13cm$). As shown in figure 7 this gives the smoothest acceptances for both signal and background and removes the step in their ratio at PC2. In figure 8 the same is shown versus lifetime. The relative background level is slightly higher than that of the two previous cuts but has the least deviations from being flat. This cut is subsequently refered to as the "radius" cut.

4 Results using different cuts

The analysis proccedure, independent of the cut used, is :

1. Run the real data, the $\pi^+\pi^-$ MC and the semileptonic MC events through the selection
2. Correct the real data for normalization using LUT
3. Use the MC $\pi^+\pi^-$ acceptance to correct the real data lifetime and then fit assuming a flat (K^0_L) background. Note that due to the exponential decay of the K^0_S the low lifetime bump in figure 4 does not affect the fit
4. Use the background level determined above and fit the asymmetry

Under the assumption that events in the same region of primary phase space have the same normalization independent of the 9c fit probability, and having applied to the real data the correct regeneration correction, all results should be in agreement (within statistics due to slightly different number of events).

This proccedure has been done on the real data of the periods 25,26 and 27 one time for each of the different cuts described in the previous section. A lifetime fit is shown in figure 10. The ratios of the background values found are in agreement with what is predicted from the MC $\pi^+\pi^-$ and semileptonic acceptances. The asymmetries are fitted using the PDG94 Δm and τ_s values. The results are summarised in table 1.

One can see that as the higher probability cut is introduced and then its start in lifetime is moved effectivelly to earlier lifetimes ϕ_{+-} moves to lower values. Note that between the cuts

Prob. Cut	Bgr. ($\times\|\eta_{+-}\|^2$)	$\|\eta_{+-}\|(\times 10^{-3})$	ϕ_{+-}	ϕ_{+-}(CPLΔm)
flat 5%	4.0 ± 0.1	2.180 ± 0.045	$45.45^0 \pm 0.94^0$	43.68^0
flat 25%	2.7 ± 0.1	2.196 ± 0.047	$45.53^0 \pm 1.00^0$	43.73^0
flat 40%	2.1 ± 0.1	2.190 ± 0.050	$45.28^0 \pm 1.06^0$	43.44^0
lft 6	1.5 ± 0.1	2.165 ± 0.045	$44.74^0 \pm 0.95^0$	42.95^0
lft 4	1.7 ± 0.1	2.199 ± 0.047	$44.06^0 \pm 0.98^0$	42.28^0
rad. 40%	2.1 ± 0.1	2.214 ± 0.046	$43.84^0 \pm 0.96^0$	42.05^0

Table 1: P25 to P27 results with different prob. cuts. The last column is the ϕ_{+-} value using the CPLEAR semileptonic published value Δm=0.5274

Prob. Cut	Bgr. ($\times\|\eta_{+-}\|^2$)	$\|\eta_{+-}\|(\times 10^{-3})$	ϕ_{+-}	ϕ_{+-}(CPLΔm)
flat 5%	4.0	2.233 ± 0.062	$43.56^0 \pm 1.24^0$	41.85^0
flat 40%	2.1	2.222 ± 0.071	$43.03^0 \pm 1.48^0$	41.21^0

Table 2: P28 results with flat prob. cuts. The last column is the ϕ_{+-} value using the CPLEAR semileptonic published value Δm=0.5274

"lft 6" and "radius" the only difference is an average of 10% of events in the region 4–6τ_s. Similar discrepancies have been observed also in part of the P28 data.

We also observe the stability of the results if a constant cut is applied at different levels (5%–40%). This consistency was also verified on part of the P28 data (6,700 runs) and is shown in table 2.

5 The difference in the "lft 6" and "radius" samples

In figure 11 the substraction of the two total samples is shown in lifetime, demonstrating that all difference is in the 4–6τ_s region. In figure 12 these events are shown as precentage of the total rates (top); the lower part shows the relative change in normalization (after LUT corrections) resulting from the inclusion of these extra events in the total sample. Figure 13 shows the $\pi^+\pi^-$ asymmetry in the 3–7τ_s region for the "radius" cut and superimposed the same for the extra events of the "lft 6" sample. These events have an overall normalization different by 3%, which taking into account that on the average they represent 10% of the sample their inclusion results in a change of normalization of 0.3%.

Indeed, if one modifies the asymmetry fitting function to use a normalization factor different by 0.3% in the 4–6τ_s region, then the ϕ_{+-} value from the "lft 6" and "radius" samples come out the same. And if all of the events in the 4–6τ_s region are excluded from both fits, the fitted value of ϕ_{+-} again is the same for the two.

In figure 14 the extra events are shown (linear z scale) versus P_T and decay R_{TR} of the neutral Kaon. They lie after PC2 and at high values of neutral kaon P_T. This is demonstrated better in figure 15, where for the 4–6τ_s region one sees the P_T distribution of the "radius" sample and the extra events. The high P_T value implies that due to the available phase space, these extra events have a central neutral kaon with respect to z (maximum angle of $\approx 35^0$ out of the P_T plane compared to our total acceptance of 72^0).

By comparing the "lft 4" and "radius" cut sample results, which are largely equivalent in terms of signal events and background, we can conclude that the variation of physics results presented in table 1 is not due to the expression of a probability cut directly on radius or directly on lifetime; it is due to low probability events.

Some possibilities which have been proposed but can be excluded are :

- Some correlation to the M1/M2 problem; however the effect does not appear in opposite way in M1,M2 and is he same in M3/M4. So it is mainly a physical rather than a geometric effect.
- A possible bias in the algorithm of the 9c fit or in its technical realization in software
- Bad coherent regeneration correction for different momenta; effects bigger by at least an order of magnitude than our total correction are needed and this is highly unprobable
- Diffractive regeneration or non elastic interactions of neutral kaons; in this case one should see normalization changes at the PCs and at 20cm. No such steps are visible within available statistics

The stability of results with different constant probability cuts further disproves the last three of the above points.

6 Normalization dependence on 9c probability

6.1 Change of the M1/M2 overall ratio

Higher probability cuts remove slightly more M2 than M1 events (difference of absolute value of the field ?). This is shown in figure 16 as function of lifetime for the real data. The change in the M1/M2 total rates is $(2.4 \pm 0.4) \times 10^{-3}$ going from a 5% to a 40% 9c probability cut.

6.2 Change in the overall normalization factor

In figure 17 the asymmetry A_{+-} is shown for the real data before the LUT correction, for the events above 40% and in the 5%–40% probability regions. One can see the difference in the overall factor. Note that almost all of these events have a decay inside the PCs. The same can be seen in figure 18, where the distribution of correction factors in the bins of the primary kinematical variables are plotted. The top two distributions are for all events above 5% probability and above 40% respectively. The slight shift between the two is evident in the lower plot, which shows the same distribution only for events with a 9c probability in the 5%–40% region. If one takes the two lower LUTs and substracts the correction factors bin by bin, then figure 19 is obtained. A mean value difference of $\approx 2\%$ is seen, the same as in figure 17.

6.3 Momentum dependence of the change

By changing the probability cuts, not only the overall M1/M2 and $\overline{\mathrm{K}^0}/\mathrm{K}^0$ ratios change, but also the shapes described in the LUTs are modified. In figure 20 the shape change is shown versus the $\mathrm{K}^\pm$ total momentum, when one goes from a 5% to a 40% 9c prob. cut. The momentum dependence is more pronounced in M1. One can make an average, shown in the lower part of this figure. The same is plotted in figure 21 as function of the $\pi^\pm$ momentum. Finally figure 22 shows the effect as function of the neutral kaon transverse momentum.

7 Resolution and normalization

Up to now it has been shown that the normalization is different for events with different reconstruction quality (translated to $P(\chi^2)$ by the 9c fit). The sensitivity of the χ^2 of the fit on the secondaries reconstruction changes for decays inside/outside the PCs, due to the smaller number of hits covering a smaller arc of the trajectories in the latter case. However the observed effect seems to be consistent in the two distinct radial regions. Moreover the symmetry of the $\pi^+\pi^-$ final state for K^0 and $\overline{\mathrm{K}^0}$ events should cancel any problem from the decay reconstruction : for a given neutral kaon kinematics it must be impossible to distinguish the K^0 from the $\overline{\mathrm{K}^0}$ samples. So one is led to suspect the reconstruction of the primary $\mathrm{K}^\pm\pi^\mp$ pair as being the origin of the observed effects.

7.1 The idea

In the presence of different interactions of $\mathrm{K}^\pm$ or $\pi^\pm$ or both with the material in the tracking volume of the experiment or in the backscatters which may interfere with the real tracks reconstruction, we can have a different resolution for $\mathrm{K}^\pm\pi^\mp$ and $\mathrm{K}^\mp\pi^\pm$ events. This under perfect conditions should be taken care for in the track fit error matrix and cause no further problem. However we know since a long time that our errors are not gaussian and the tails are not perfectly described. In such a case part of the underlying resolution difference may be translated to an asymmetry in the probability distributions of the 9c (and in principle in all other fits).

As a result the normalization is not completely described by the kinematics of the primaries; one or more extra dimensions describing their reconstruction quality should also be used.

7.2 Demonstration

A variable which describes the reconstruction quality of only the primary particles is the probability of the 1c fit (missing mass $= m_{K^0}$). The scheme presented above is supported by figures 23 and 24. The variable plotted is the normalization of events in bins of 1c probability. The plots were done for all events with a probability above 5% in the 9c fit. To be free of any background effect only events in the 1–4τ_s region were used. This also ensures that in all cases the decay happened before PC2. The usual LUT correction was applied, so the plots show the relative normalization of events and not the absolute one. The main momentum dependencies have also been taken care for by the LUT. One plot per (trigger) period is shown in figure 23 and the average for all P25–P27 data is shown in figure 24.

8 Further study

A possible solution, to add an extra dimension to the current LUTs (1c probability) or even two (kaon and pion momentum correction by the fits), has proven to be not realistic due to statistics (too many bins). Moreover, since the probability cuts change the average $\overline{\mathrm{K}^0}/\mathrm{K}^0$ *and* M1/M2 factors *and* the shapes described in the LUTs, to apply an overall correction as function of the 1c probability is not trivial. The probability distribution of events at different lifetime and radius regions should be studied on the full statistics of P25–P28, and if significant variation is observed then a way to correct for this should be found.

The ideal would be to understand and parametrize the normalization dependence on probability in such a way that the results obtained with any cut are in agreement. This would then allow to export the LUTs *and* the overall normalization factor from $\pi^+\pi^-$ to other final states, which would allow to reduce errors on some measurements.

In order to do this study and to facilitate other stability and consistency checks, a new compact and flexible format (nano DST) is in preparation.

References

[1] CPLEAR/NORM-008

[2] CPLEAR/NORM-009

[3] CPLEAR/NORM-010

[4] PPE/PS195/CT/96-001 , $\pi^+\pi^-$ note number 7

[5] CPLEAR/HWP-028

9 Figures

Figures are grouped at the end of the report to facilitate reading

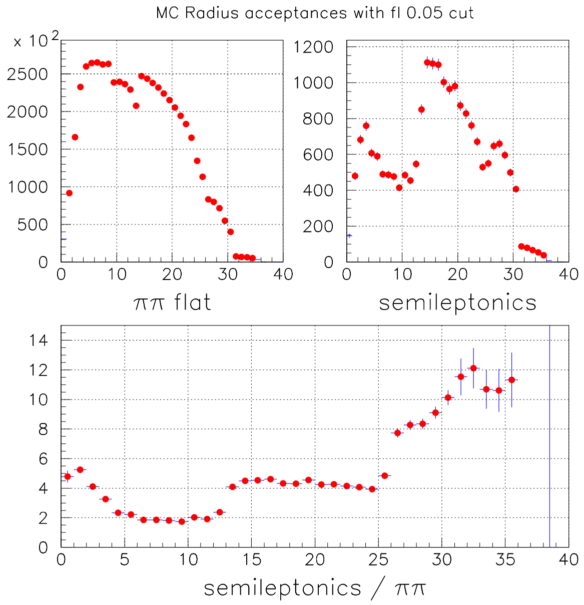

Figure 1: Signal (left) and background (right) acceptances of the 9c fit with a flat 5% prob. cut and their ratio (lower plot) , all in radius

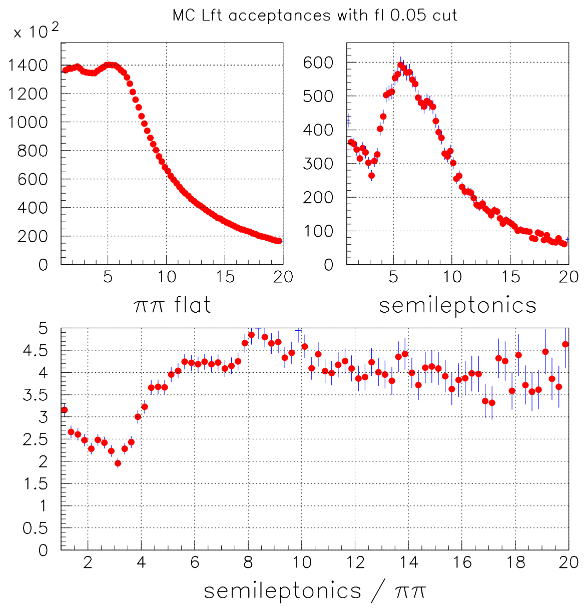

Figure 2: Signal (left) and background (right) acceptances of the 9c fit with a flat 5% prob. cut and their ratio (lower plot) , all in lifetime

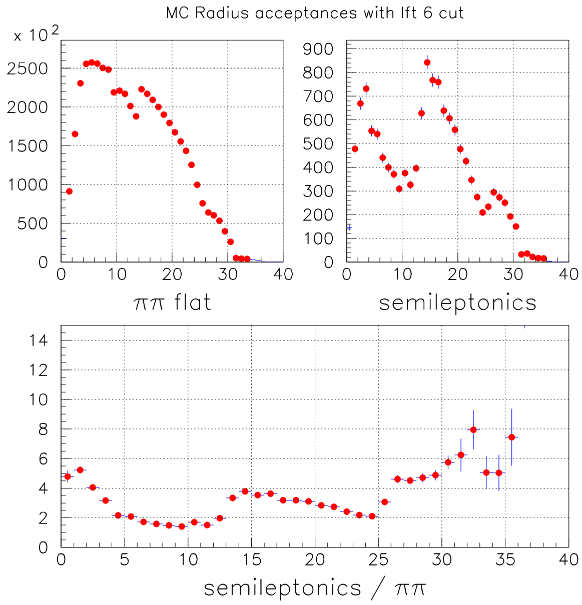

Figure 3: Signal (left) and background (right) acceptances of the 9c fit with the "lft 6" prob. cut and their ratio (lower plot) , all in radius

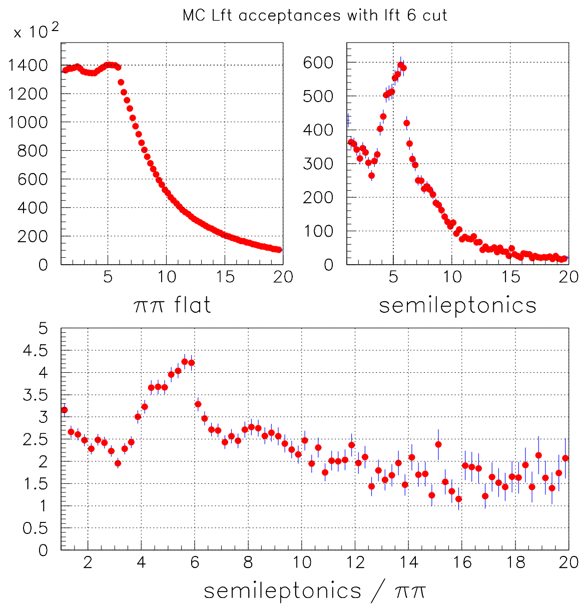

Figure 4: Signal (left) and background (right) acceptances of the 9c fit with the "lft 6" prob. cut and their ratio (lower plot) , all in lifetime

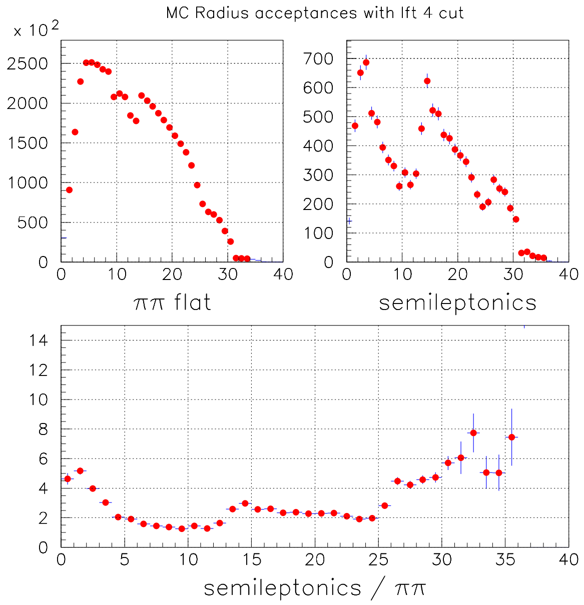

Figure 5: Signal (left) and background (right) acceptances of the 9c fit with the "lft 4" prob. cut and their ratio (lower plot) , all in radius

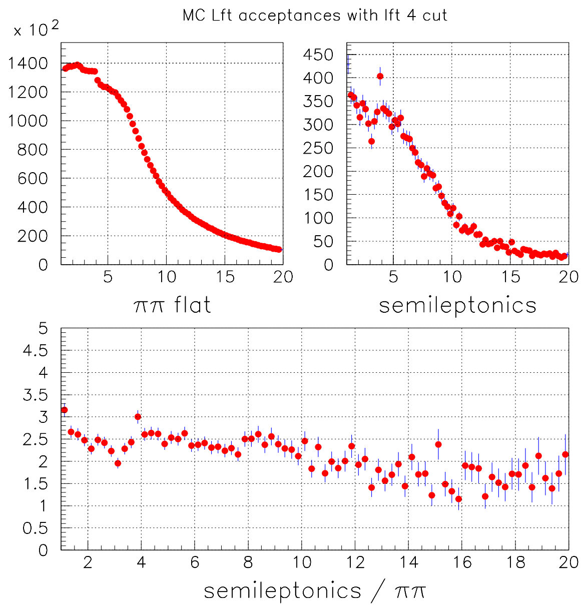

Figure 6: Signal (left) and background (right) acceptances of the 9c fit with the "lft 4" prob. cut and their ratio (lower plot) , all in lifetime

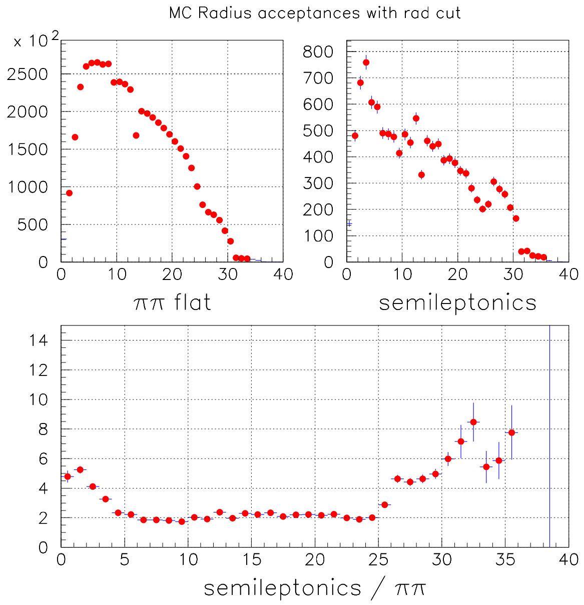

Figure 7: Signal (left) and background (right) acceptances of the 9c fit with the radius prob. cut and their ratio (lower plot) , all in radius

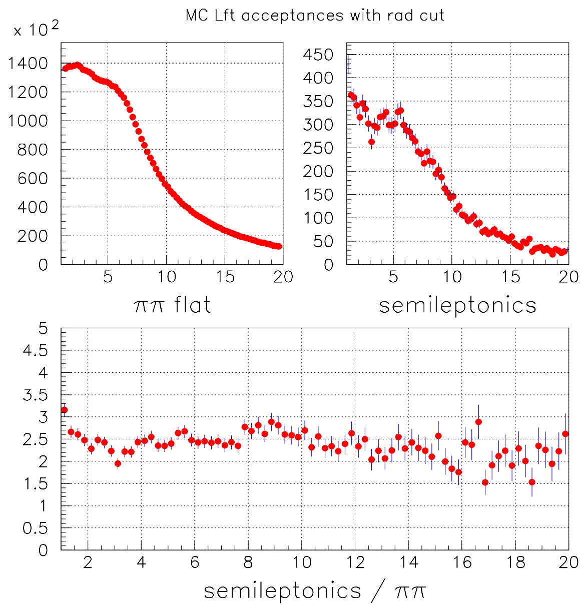

Figure 8: Signal (left) and background (right) acceptances of the 9c fit with the radius prob. cut and their ratio (lower plot) , all in lifetime

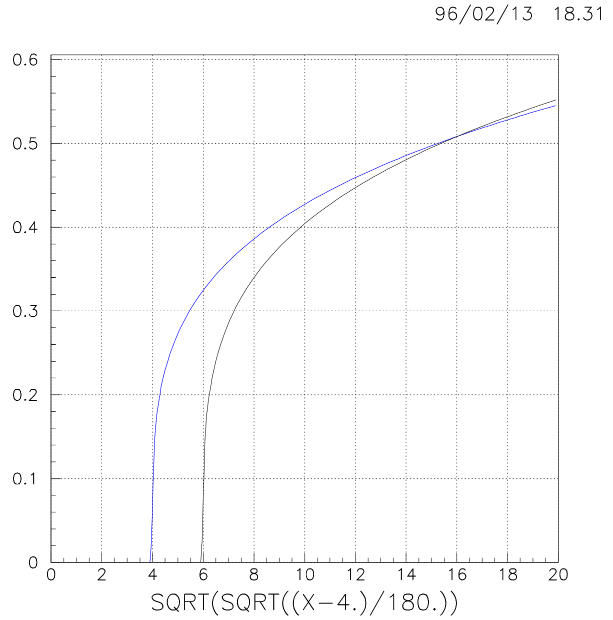

Figure 9: The probability cuts versus lifetime, "lft 6" starting at $6\tau_s$ and "lft 4" starting at $4\tau_s$

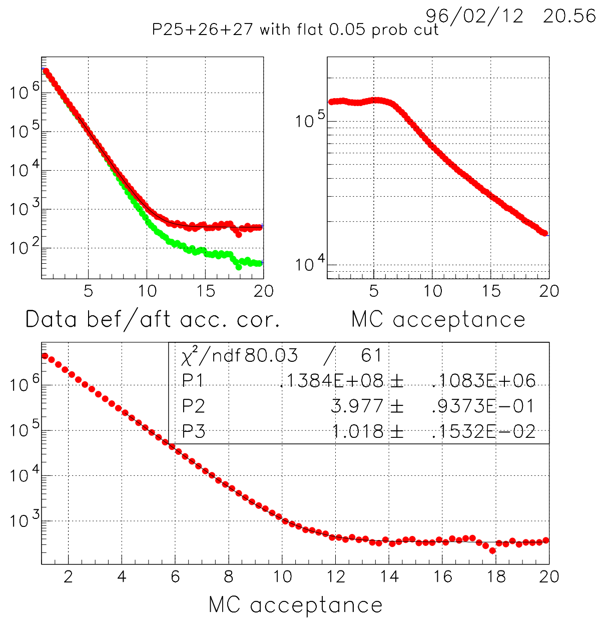

Figure 10: The data before and after correction (left), the MC acceptance used (right) and the lifetime fit (lower) for the flat 5% cut in prob.

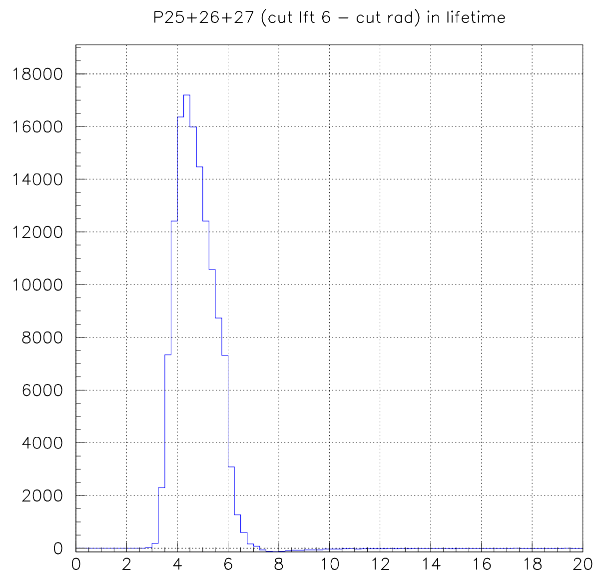

Figure 11: Substraction of total decay rates ("lft 6" – "radius" cuts)

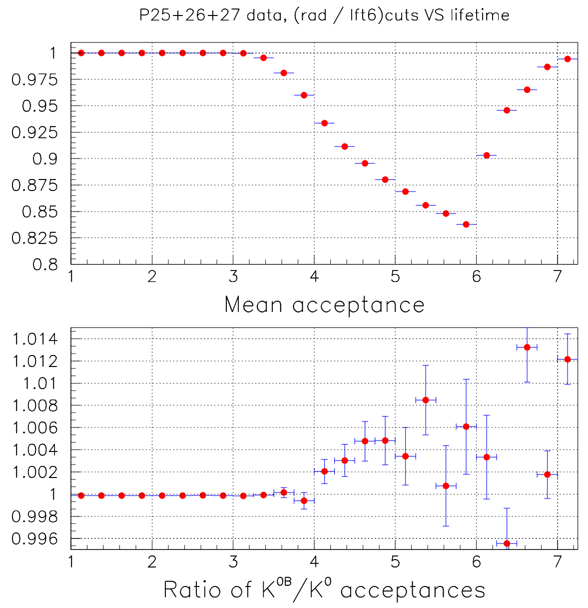

Figure 12: The extra events ("lft 6" – "radius" cuts) as a percentage in lifetime (top) and the relative change in normalization resulting from their inclusion (lower)

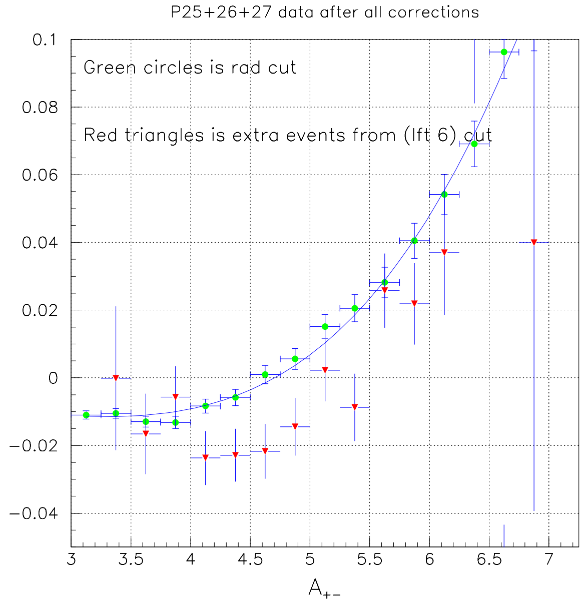

Figure 13: A_{+-} (3–7τ_s) for the "radius" cut events and for the extra "lft 6" events

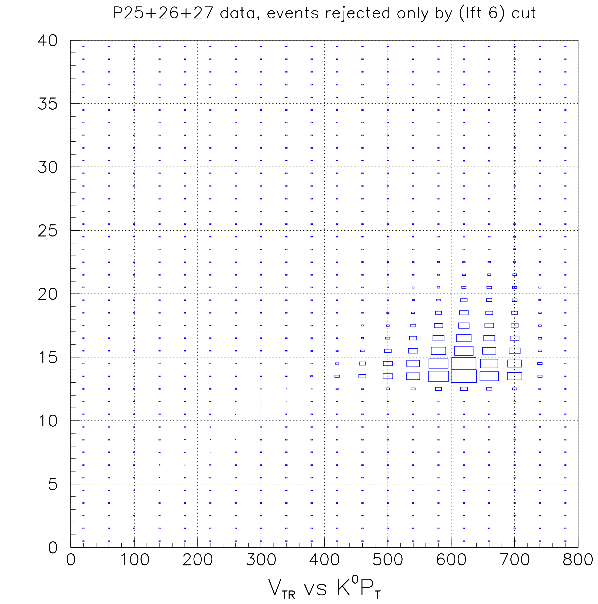

Figure 14: The extra events in decay radius – P_T of neutral kaon

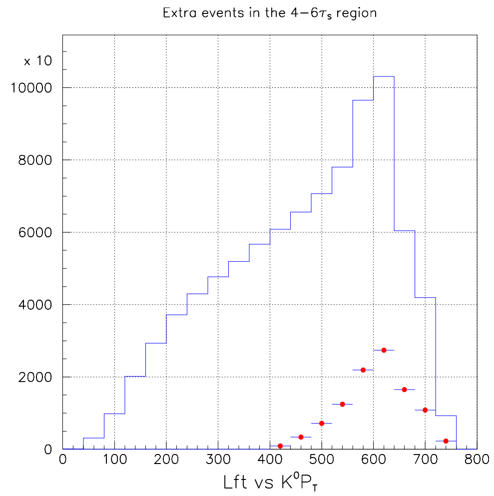

Figure 15: P_T of neutral kaon of all events in the 4–6τ_s region (line) and of the extra events (dots)

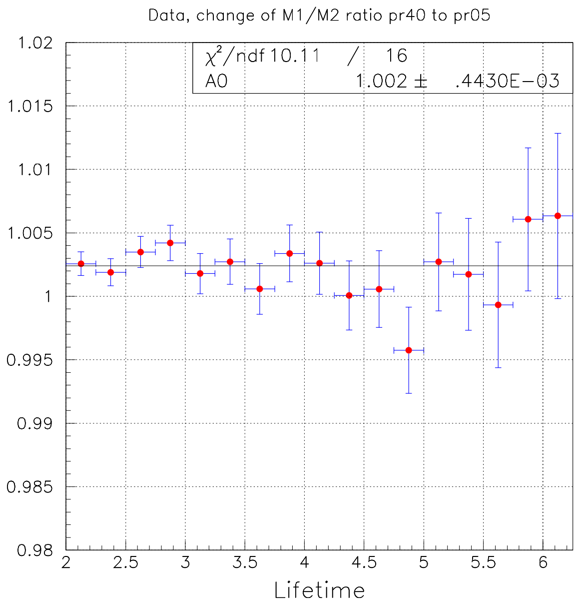

Figure 16: Going from a flat 5% to a flat 40% prob. cut in the 9c fit : change in the overall M1/M2 event ratio vs lifetime

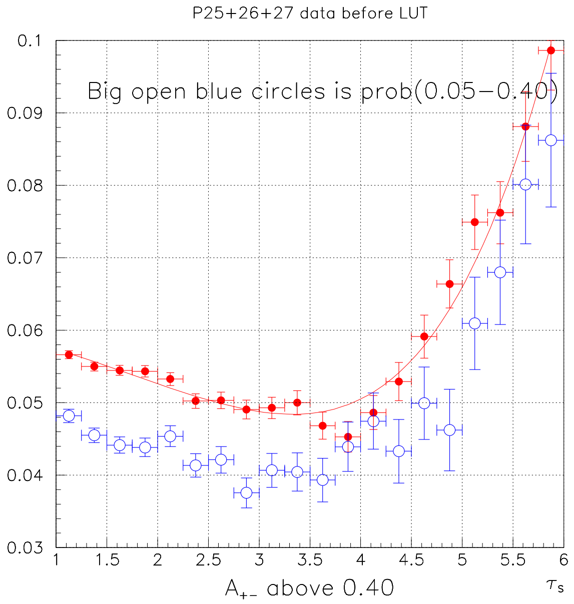

Figure 17: A_{+-} for events above 40% and in the 5%–40% 9c prob. region, before LUT correction

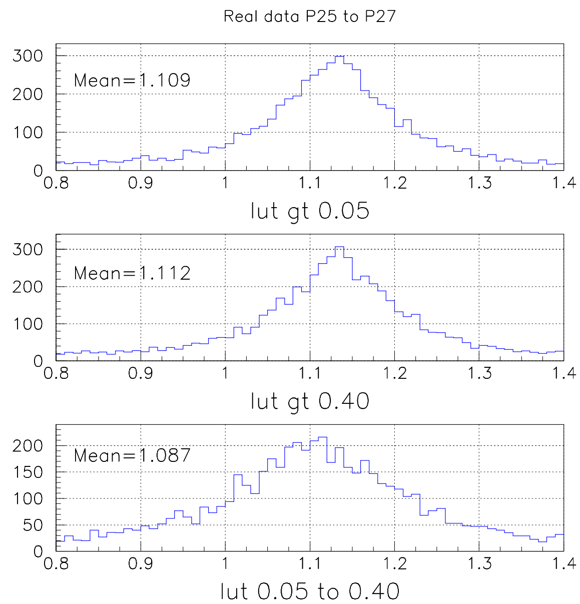

Figure 18: LUT values for events above 5%, above 40%, and only in the 5%–40% 9c prob. region

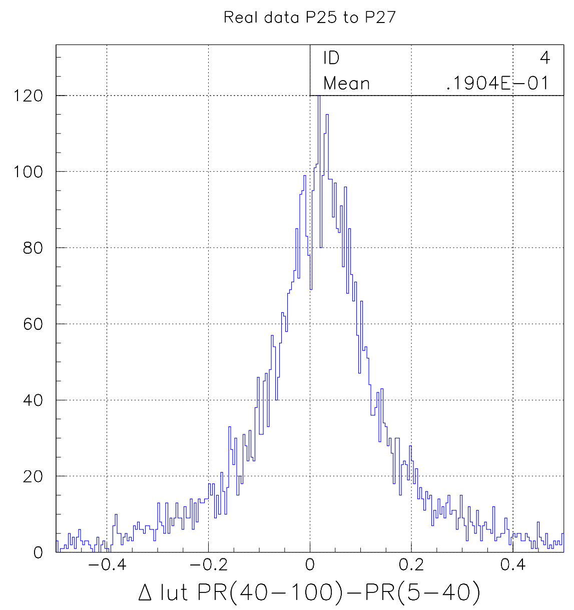

Figure 19: Bin by bin LUT value difference for events above 40% and in the 5%–40% 9c prob. region

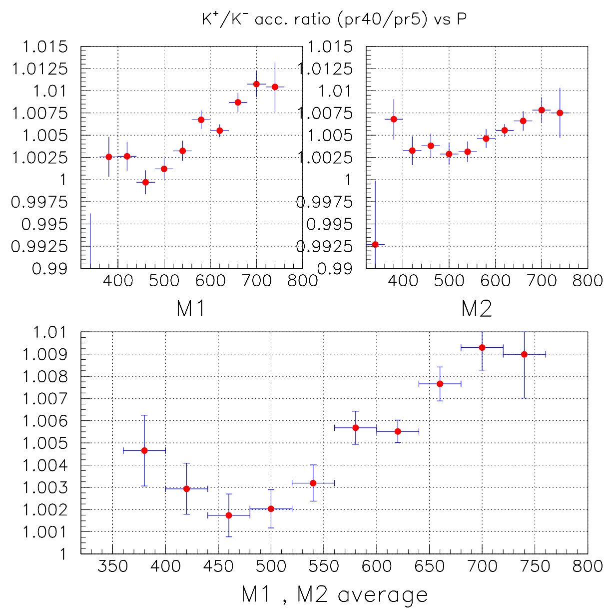

Figure 20: Going from a flat 5% to a flat 40% prob. cut in the 9c fit : change in the normalization vs $P(K^{\pm})$

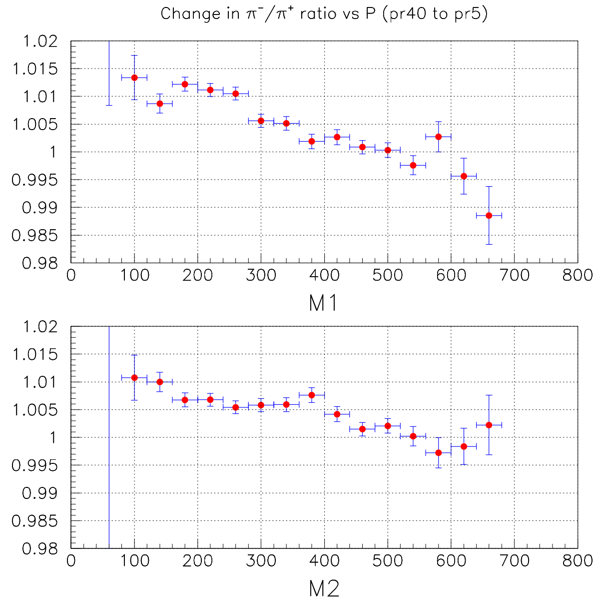

Figure 21: Going from a flat 5% to a flat 40% prob. cut in the 9c fit : change in the normalization vs P($\pi^{\pm}$)

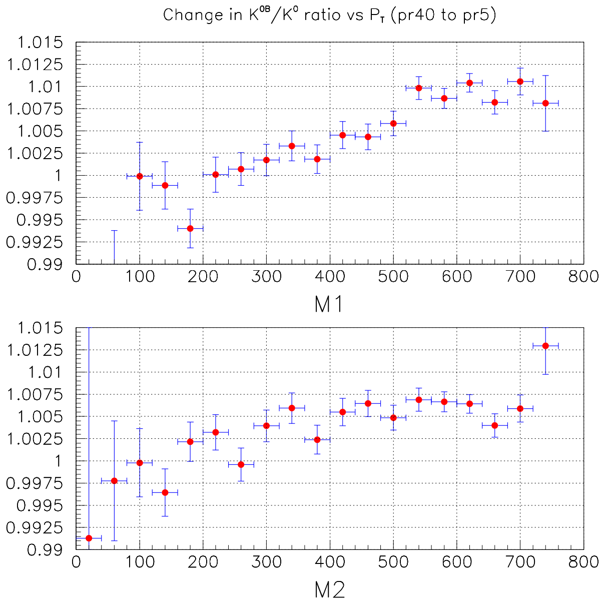

Figure 22: Going from a flat 5% to a flat 40% prob. cut in the 9c fit : change in the normalization vs P_T of the neutral kaon

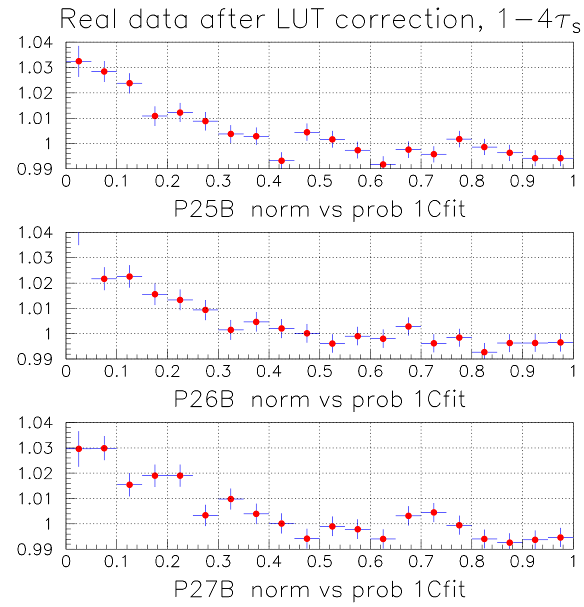

Figure 23: Average normalization after LUT correction vs 1c fit probability for three different periods

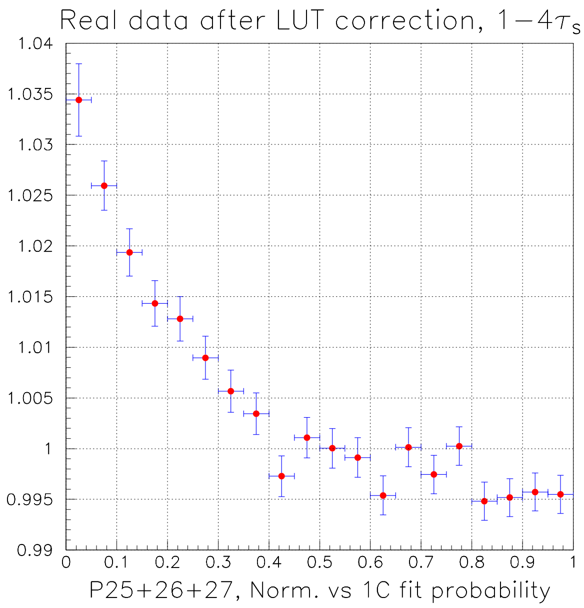

Figure 24: Average normalization after LUT correction vs 1c fit probability for P25 to P27 data