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A preliminary study of $K_S^\circ \rightarrow \pi \mathbf{l} \nu$

G.Finocchiaro

Abstract

A preliminary GEANFI study of the reaction $K_S^\circ \rightarrow \pi l \nu$ is presented. The required rejection factor against the $K_S^\circ \rightarrow \pi^+\pi^-$ decay is derived, as well as the necessary π-μ separation. An analysis based on p and track length measurements in the drift chamber, and on the impact point and TOF on the calorimeter indicates that the measurement is well within KLOE's possibilities.

1 Introduction

The interest of the never observed $K^\circ_S \to \pi l \nu$ decays has been stressed by many authors [1, 2]. When compared to the analogous K°_L reaction, a simultaneous $\mathcal{CPT}$ and $\mathcal{T}$ test is possible, which is unique to a $\phi - factory$. The leptonic asymmetries can be written as:

$$\mathcal{A}_S \equiv \frac{\Gamma_S^{l^+} - \Gamma_S^{l^-}}{\Gamma_S^{l^+} + \Gamma_S^{l^-}} \simeq 2\Re e\,(\varepsilon_S) - 2\Re e\,(y) + \Re e\,(x - \bar{x}) \tag{1a}$$

$$\mathcal{A}_L \equiv \frac{\Gamma_L^{l^+} - \Gamma_L^{l^-}}{\Gamma_L^{l^+} + \Gamma_L^{l^-}} \simeq 2\Re e\,(\varepsilon_L) - 2\Re e\,(y) - \Re e\,(x - \bar{x}) \tag{1b}$$

where y parametrizes $\mathcal{CPT}$ violation in the decay, and x $(\bar{x})$ the violation of the $(\Delta S = \Delta Q)$ rule for K° $(\bar{K}^\circ)$ decays.

The Kabir asymmetry [3] measures $\mathcal{T}$ violation in the $K^\circ - \bar{K}^\circ$ system by comparing the rates for the $\mathcal{T}$-conjugated processes $K^\circ \to l^+X$, $\bar{K}^\circ \to l^-X$. At a $\phi - factory$ this can be done by counting same-sign dilepton events $l^{\pm\pm}$:

$$\mathcal{A}_{\mathrm{Kabir}} = \frac{\Gamma_S^{l^+}\Gamma_L^{l^+} - \Gamma_S^{l^-}\Gamma_L^{l^-}}{\Gamma_S^{l^+}\Gamma_L^{l^+} + \Gamma_S^{l^-}\Gamma_L^{l^-}} = 4\Re e\,(\varepsilon) - 4\Re e\,(y), \tag{2}$$

which happens to be equal to $\mathcal{A}_S$+$\mathcal{A}_L$. In other words $\mathcal{A}_{\mathrm{Kabir}}$ measures the ε parameter resulting from $\mathcal{T}$ violation, which has to be equal to ε from $\mathcal{CP}$ violation in $K^\circ - \bar{K}^\circ$ mixing, if $\mathcal{CPT}$ is conserved.

2 Expected number of events and rejection factor

Assuming the $\Delta S = \Delta Q$ rule, the $\mathcal{BR}$ of $K^\circ_S \to \pi l \nu$ is:

$$\mathcal{BR}(K^\circ_S \to lX) = \frac{\Gamma_L}{\Gamma_S}\mathcal{BR}(K^\circ_L \to lX) \simeq 1.1 \cdot 10^{-3}. \tag{3}$$

For an integrated luminosity $L = 10^{10}\,\mu b^{-1}$, this corresponds to $N_{K^\circ_S \to lX} \simeq 4 \cdot 10^6$ events. The statistical error on the small asymmetry $\mathcal{A}_S$ is

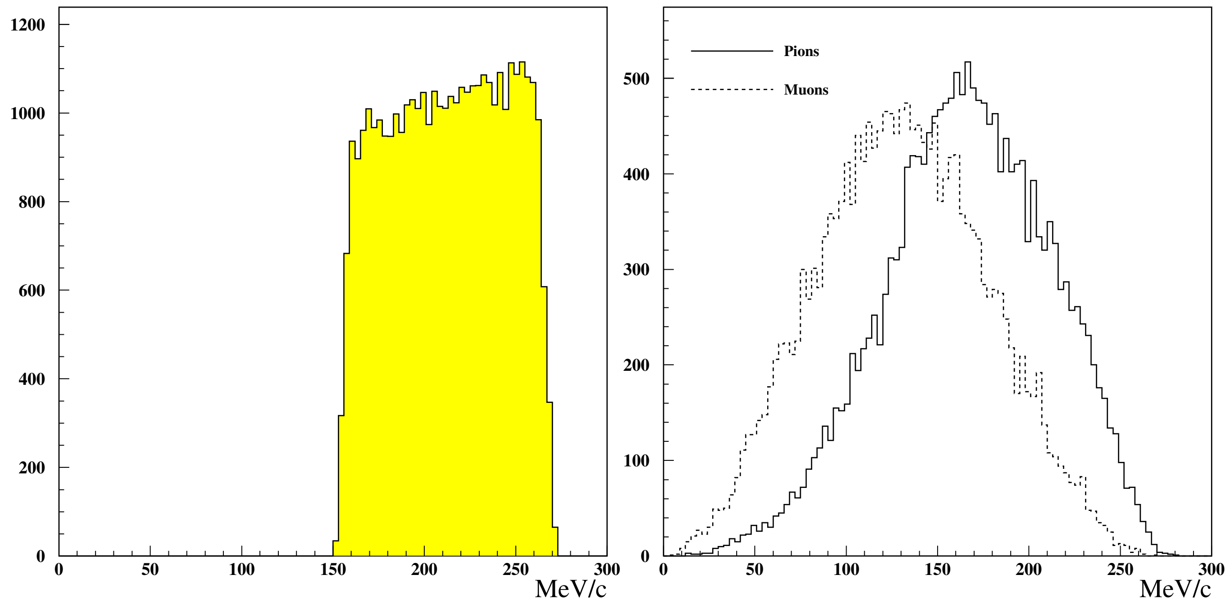
$$(\delta\mathcal{A}_S)_{\mathrm{STAT}} = 1/\sqrt{N_{K^\circ_S \to lX}} \simeq 5 \cdot 10^{-4}, \tag{4}$$

therefore $(\delta\varepsilon_S)_{\mathrm{STAT}} = 2.5 \cdot 10^{-4}$.

The most relevant background to $K^\circ_S \to \pi l \nu$ is the decay $K^\circ_S \to \pi^+\pi^-$, amounting to 68.6% of the total K°_S decay rate. With a little algebra the asymmetry dilution due to the $K^\circ_S \to \pi^+\pi^-$ background is derived:

$$\mathcal{A}_S^{oss} = \frac{\mathcal{A}_S}{1 + \mathcal{R}_{\mathcal{BR}} \cdot \mathcal{R}_J} \tag{5}$$

$\mathcal{R}_{\mathcal{BR}} = 618$ is the ratio of background to signal branching ratios, $\mathcal{R}_J = \varepsilon_\pi/\varepsilon_\mu$ is the needed rejection factor. For a change $\delta\mathcal{R}_J$ in the rejection factor the change in $\mathcal{A}_S$ is $\delta\mathcal{A}_S \simeq \mathcal{A}_S\mathcal{R}_{\mathcal{BR}}\delta\mathcal{R}_J \simeq 2 \cdot \delta\mathcal{R}_J$,



(a) $K^\circ_S \to \pi^+\pi^-$.

(b) $K^\circ_S \to \pi\mu\nu$.

Figure 1: *Momentum spectra from charged decays of* K°_S.

assuming $\mathcal{A}_S$=$\mathcal{A}_L$=3.3·10^{-3}. Imposing the error due to background rejection to be n times less than the statistical one, a limit for $\mathcal{R}_J$ is derived:

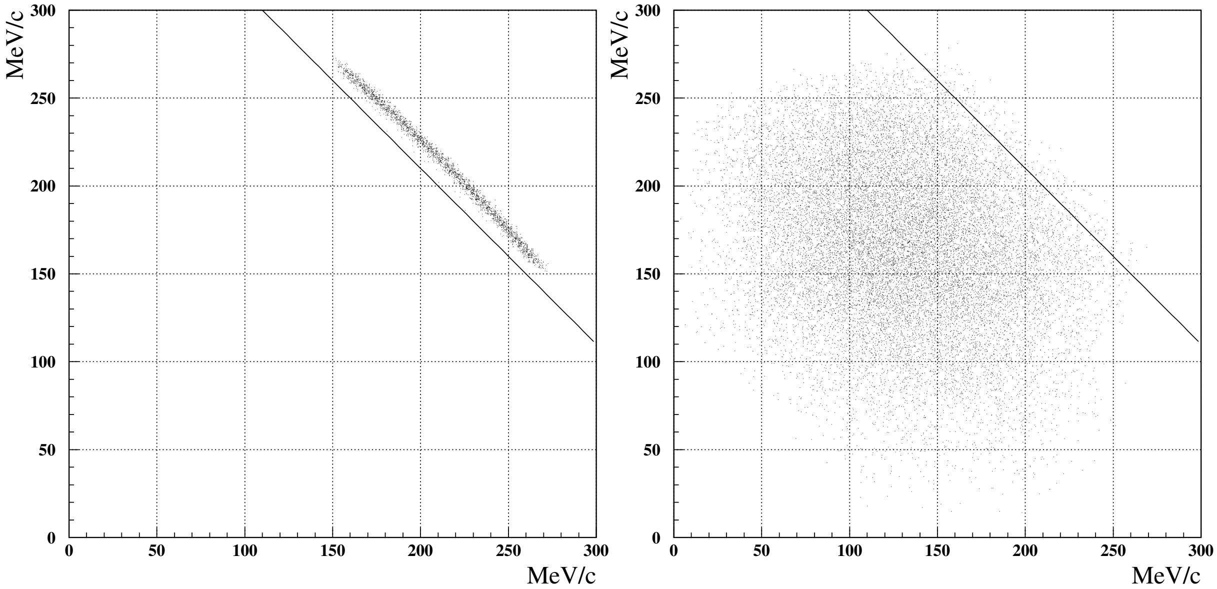
$$\mathcal{R}_J \leq \frac{1}{\mathcal{R}_{BR}} \cdot \frac{1}{n\alpha} \left(\frac{\delta\mathcal{A}_S}{\mathcal{A}_S}\right)_{STAT} = 5.4 \cdot 10^{-4} \tag{6}$$

if $n = 3$, $(\delta\mathcal{A}_S/\mathcal{A}_S)_{STAT} = 0.1$. $\alpha = \delta\mathcal{R}_J/\mathcal{R}_J$ is the precision with which the rejection factor is known, assumed here 10%.

3 $K^\circ_S \to \pi^+\pi^-$ rejection

In the following we shall concentrate on the $K^\circ_S \to \pi\mu\nu$ channel. Since the electron mass much lower than the pion and muon mass, kinematically the muon case is indeed expected to be the most difficult one. For the study a modified version of GEANFI13_3, allowing the decays $K^\circ_S \to \pi l \nu$[1] has been used. 1.0·10^5 $K^\circ_S \to \pi^+\pi^-$ and 1.6·10^5 $K^\circ_S \to \pi\mu\nu$ events have been generated. The characteristic 2-body and 3-body momentum distribution are shown in fig. 1. Of greater help to discriminate between signal and background is the correlation between the momenta of the 2 charged tracks from K°_S, shown in fig. 2. The continuous line represents a cut on the total momentum $|p|_1 + |p|_2 \leq 410\,\mathrm{MeV}/c$. Efficiency, purity and rejection factor for this cut are listed in tab. 1 for different values of the $\delta(1/p_\perp)/(1/p_\perp)$ resolution,

[1] Now this has been implemented as a standard feature.



(a) $K^\circ_S \to \pi^+\pi^-$.

(b) $K^\circ_S \to \pi\mu\nu$.

Figure 2: *Correlation between the momenta of the charged track decay products of* K°_S.

assumed Gaussian. It is not surprising that, while the elimination of the $K_{\mu 3}$ background to the $\mathcal{CP}$ violating decay $K^\circ_L \to \pi^+\pi^-$ constitutes one of the most challenging problems in KLOE, we got rid of our $K^\circ_S \to \pi^+\pi^-$ background with a simple cut on the total energy. 3-body decays have indeed tails, where the neutrino is emitted with very low energy, and are kinematically very similar to the 2-body distribution. Of course (apart from resolution effects) 2-body decays do not have 3-body-like tails!

$\sigma(1/p_\perp)/(1/p_\perp)$	ϵ_π	ϵ_μ	κ
0	0	0.986	0
0.003	0	0.986	0
0.01	$4.26 \cdot 10^{-5}$	0.986	$4.32 \cdot 10^{-5}$

Table 1: *Signal and background efficiencies for the cut* $|p|_1 + |p|_2 \leq 410\,MeV/c$ *for different momentum resolutions.*

4 π-μ rejection

Assuming to be left with only $\mathrm{K_S^\circ} \to \pi\mu\nu$ events, in order to measure the lepton charge asymmetry one has to tell the muon from the pion.

If only one of the two particles were misassigned, the event would be discarded as a 2-μ or 2-π one. So therefore, only double misassignements affect $\mathcal{A}_\mathrm{S}$. Calling ϱ the confusion probability, the usual little algebra yields:

$$\mathcal{A}_\mathrm{S}{}^{obs} \simeq \mathcal{A}_\mathrm{S}(1 - 2\varrho^2). \tag{7}$$

The error associated with a fluctuation $\delta\varrho^2 = 2\varrho\delta\varrho$ of the confusion probability is

$$\delta\mathcal{A}_\mathrm{S}{}^{obs} \simeq \delta\mathcal{A}_\mathrm{S} = 4\mathcal{A}_\mathrm{S}\frac{\delta\varrho}{\varrho}\varrho^2. \tag{8}$$

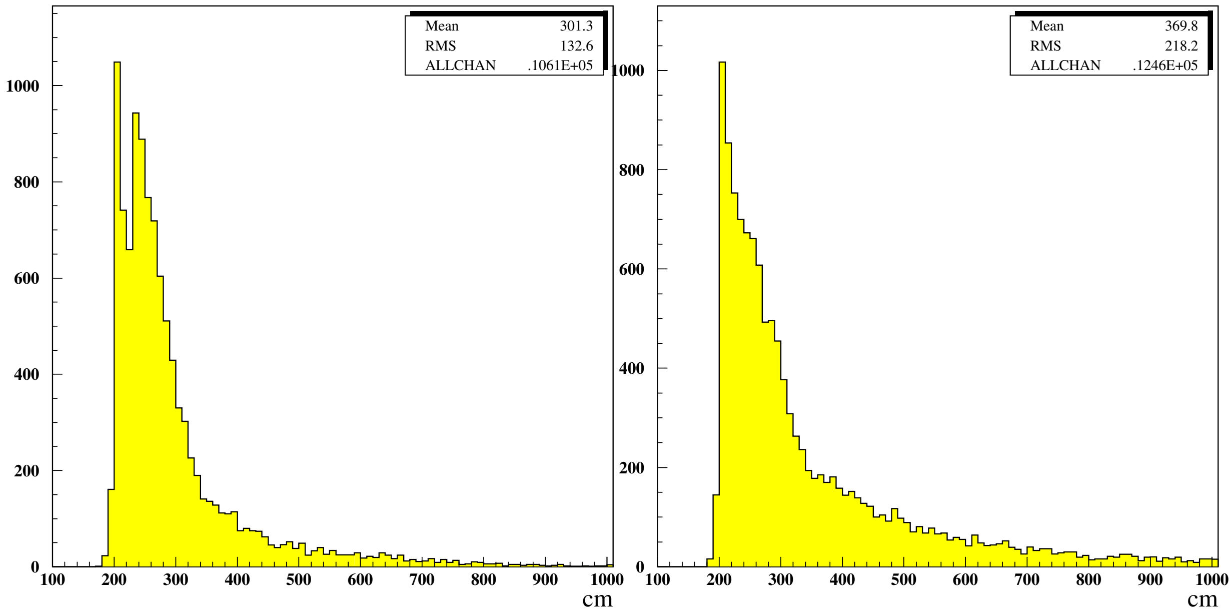
Requiring again this error to be $n = 3$ times smaller than the statistical one and assuming $(\delta\varrho/\varrho) = 10\%$ one obtains $\varrho \leq 0.29$. If one demands not to correct at all for this effect, i.e. $\delta\mathcal{A}_\mathrm{S} = (\mathcal{A}_\mathrm{S}{}^{obs} - \mathcal{A}_\mathrm{S})$ is negligible with respect to the statistical uncertainty, the slightly more restrictive condition $\varrho \leq 0.13$ is obtained.

A combined use of information from both the drift chamber and the calorimeter allows one to reach the required π-μ separation. We restrict ourselves to non-decayed pions for the moment: the effect of the decays will be evaluated later on.

The track length distribution for pions and muons from $\mathrm{K_S^\circ}$ is shown in fig. 3. The variable is constructed summing up the GEANFI path lengths from one hit to the next one inside the drift chamber, the two helix pieces from the $\mathrm{K_S^\circ}$ decay vertex to the 1st hit in the chamber and from the last hit in the chamber to the impact point on the calorimeter. Given the long path length, the Time Of Flight distribution on the calorimeter is a good variable to discriminate π and μ. The TOF distribution is shown in fig. 4; from this and from the track length the particle velocity can be measured, which is shown vs. $|p|$ in fig. 5. Finally, from β and p one obtains the particle mass, shown in fig. 6. The tails are mostly due to energy lost traversing the chamber volume and especially the chamber walls, as it is shown in fig. 7. A mean correction has been applied in fig. 6, which still shows a systematic $\simeq 5\,\mathrm{MeV}/c^2$ lower shift in the mass distribution. Even so the confusion probability, which is given by the common area of the π and μ peaks, is $8{\cdot}10^{-3}$, a factor ~ 20 better than required in the beginning of this section.

4.1 π decays

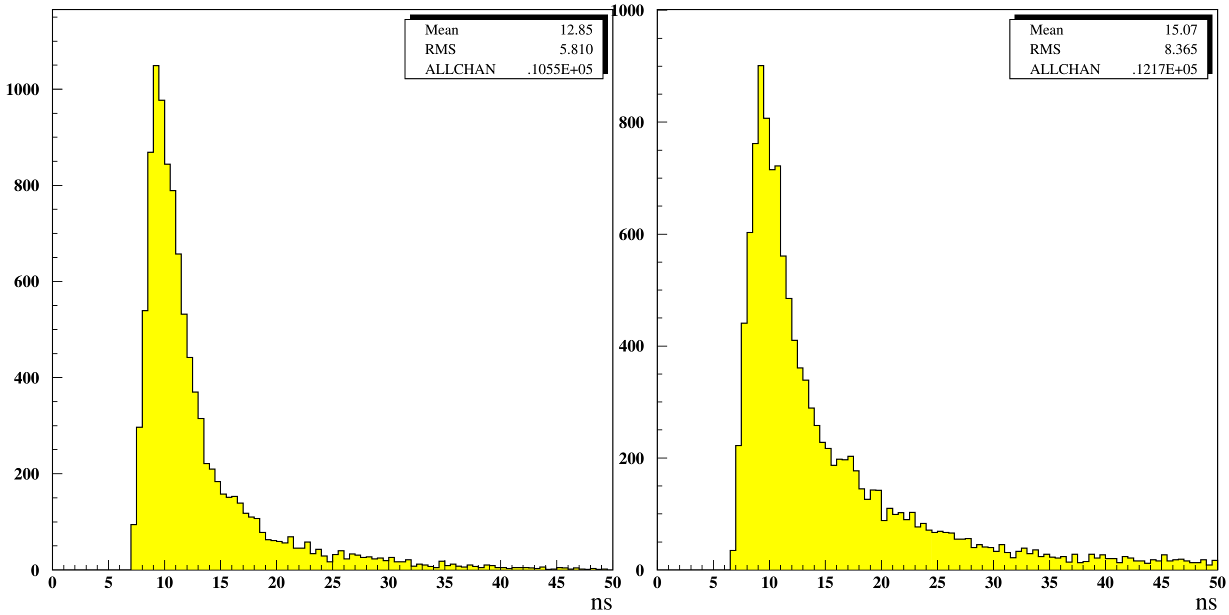
In the previous section we neglected pion decays. We give here an estimate of their effect. If the decay is detected, the particle type is readily assigned. The problem is therefore of how many pion decays remain undetected. We established the criterium that if the π-μ opening angle in the laboratory is larger than $3\sigma_{slope}$ – where σ_{slope} is the chamber angular resolution – the decay is recognised. Suppose we fit locally the track trajectory, using 5 hits ($\sim 10\,\mathrm{cm}$ in the 2×2 cells of the PSI '93 prototypes) with a spatial



(a) Pion track length.

(b) Muon track length.

Figure 3: *Track length for non decayed π and μ in $K^{\circ}_{S} \rightarrow \pi\mu\nu$. The double peak in fig. (a) is due to decays, for particles impinging onto the endcaps.*



(a) Pion Time Of Flight.

(b) Muon Time Of Flight.

Figure 4: *μ and π (non decayed) TOF distribution.*

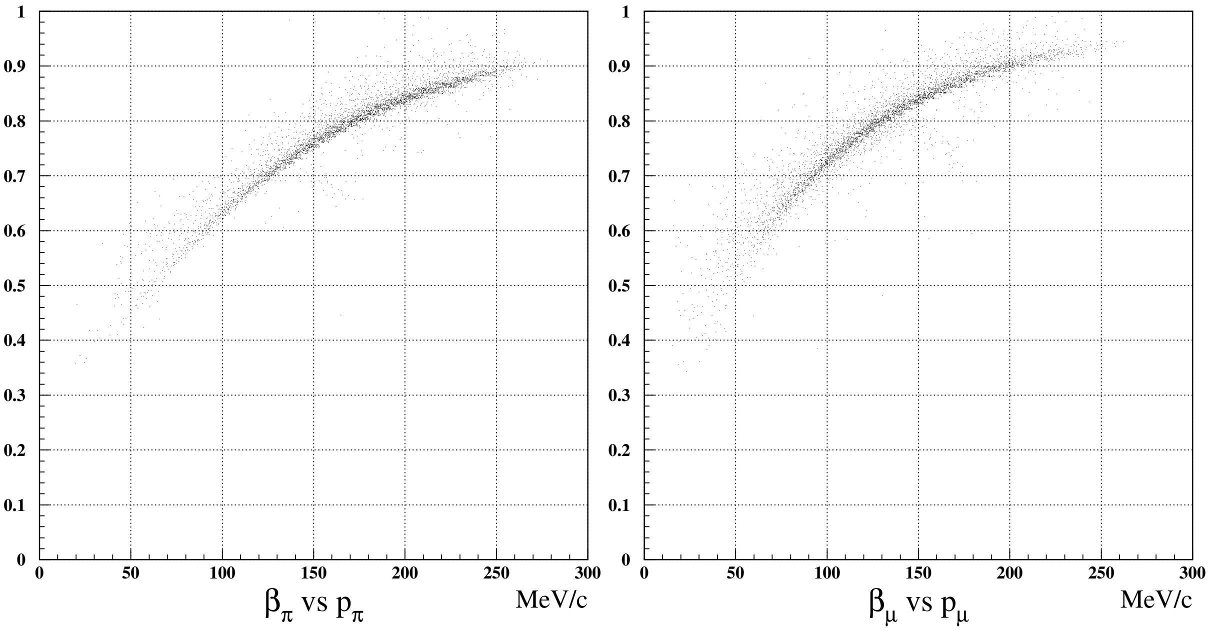
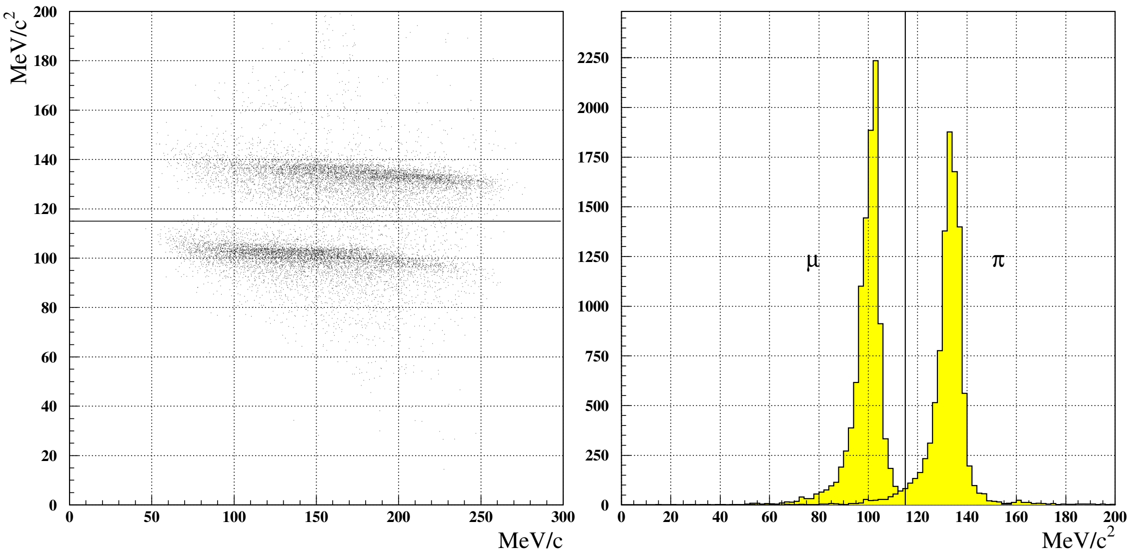


Figure 5: *β vs. $|p|$ for non decayed π and μ.*



(a) Mass vs. $|p|$.

(b) Mass spectra.

Figure 6: *Mass distribution from TOF, track length and momentum measurements of μ and π.*

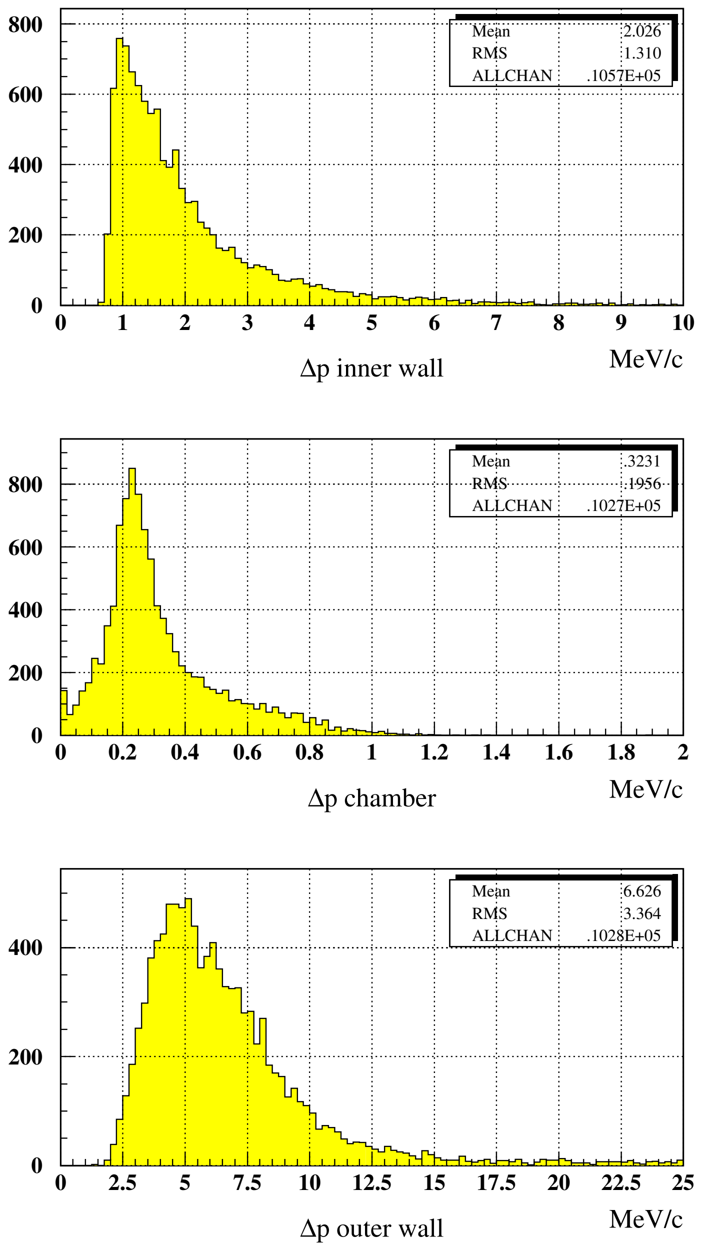


Figure 7: *Momentum lost by pions traversing respectively the beam pipe and the dc inner wall, the chamber volume, the dc outer wall.*

resolution of 200 μm. The error on the track slope due to the single cell resolution is $\sigma_{res}^{R-\phi} \simeq 3$ mrad. The multiple scattering contribution is negligible in this context, due to the short path length: $\sigma_{ms} \leq 1$ mrad assuming p=180 MeV$/c$.

The resolution in the $R-z$ plane is typically $\sigma_{res}^{R-z} \simeq \sigma_{res}^{R-\phi}/\langle\sin\vartheta_{st}\rangle \simeq 33$ mrad, therefore it is convenient to project the π-μ opening angle onto the transverse plane. This corresponds to say that the minimum angle must be $\vartheta_{min} = 14.3$ mrad. Taking into account the Lorentz transformation, we calculate that the fraction of muons emitted inside the 'invisibility cone' amounts to $1.8 \cdot 10^{-3}$ of the total pion decays[2]. How this affects the mass distributions depends on where the decay actually takes place: the later the decay, the more 'pion-like' the TOF is, and viceversa. However, the effect is very small with respect to the miximum required confusion probability.

5 Conclusions

A preliminary study has been performed on $K_S^\circ \to \pi\mu\nu$. The momentum resolution of the KLOE drift chamber is found to be sufficient to reach a rejection factor of $5.4 \cdot 10^{-4}$ against the $K_S^\circ \to \pi^+\pi^-$ decay. The maximum allowed confusion probability has been derived to be $\simeq 20\%$. The combined measurements of p, TOF and track length allow to keep this probability below the 1% level.

In-flight pion decays have not been included. The number of undetected π decays has been calculated to be $1.8 \cdot 10^{-3}$ of the total # of pions from K_S°.

Although the margins of the obtained sample purity with respect to the required one are rather large, more work is needed to perform a detailed simulation, including the effect of pion decays, non Gaussian tails, hit wires, etc.

6 Acknowledgements

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References

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[2] V.Patera, A.Pugliese, *in 'The* DAΦNE *Physics Handbook'*, INFN-LNF ed. by L.Maiani, G.Pancheri, N.Paver (1992), and references therein.

[3] P.K.Kabir, *Physical Review* **D2**, 540 (1970).

[2] With a 0.6 T magnetic field, $\sim 44\%$ of the pions from K_S°decay before reaching the calorimeters.