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Backgrounds to the $K_L^o \to \pi^o\pi^o$ channel

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Introduction

The precise measurement of ε'/ε planned at the DAFNE Φ factory requires, in order not to spoil the high statistical accuracy needed, careful control of any potentially dangerous systematic error. Two possible sources, relevant to the $K_L^o \to \pi^o\pi^o$ channel, have been studied in the present contribution, via a Montecarlo analysis focussed on the use of the time-of-flight technique for photons detected in the e.m. calorimeter:

1) Due to the exponential distribution of K_L^o decays, the number of $K_L^o \to \pi^o\pi^o$ vertices accepted inside a radially defined fiducial volume will be a function of the shape and simmetry of the resolution obtained for the radial coordinate of the vertex.

2) The main background to $K_L^o \to \pi^o\pi^o$ events will come from $K_L^o \to \pi^o\pi^o\pi^o$ events in which 2 photons have been missed, either absorbed by the material in front of the calorimeter, or out of angular acceptance. The ultimate rejection of these events will be made using constrained kinematic fits, for which energy resolution, more than spatial resolution, will be the figure of merit.

Spatial resolution and smearing effects

Even in the case of a narrow and perfectly symmetric smearing of the radial vertex coordinate, the true number of events in a given volume will systematically differ from the accepted number, and one finds analytically:

$$(N_{exp} - N_{true})/N = \frac{\sigma_r^2 e^{-r/\lambda} - \sigma_R^2 e^{-R/\lambda}}{2\lambda^2(e^{-r/\lambda} - e^{-R/\lambda})}$$

in which σ_r, σ_R are the radial resolutions at the inner and outer radii, and $\lambda = 347$ cm. For $\sigma_r = \sigma_R = 2$ cm, $r = 20$ cm, $R = 150$ cm, one predicts $\Delta N/N = 1.6 \cdot 10^{-5}$, but this number can hardly be trusted, being the (small) outcome of two delicate subtractions: the first one between the values at low radius and high radius of the *derivative* of the K_L^o decay distribution, and the second between the net balance of events at each boundary of the fiducial volume; the asimmetry of the smearing distribution can change the signs of both balances, and the presence of tails can change their absolute values, and the overall difference.

The fit procedure for the vertex of the 4 photons from $K_L^o \to \pi^o\pi^o$ tries to find a distance R_{fit} along the K_L^o flight direction (assumed known from tracking of the opposite decay $K_S^o \to \pi^+\pi^-$) that minimizes

$$\sum_{i=1}^{4}(t_i^{mes} - t_i^{th}(R_{fit}))^2/\sigma_i(t)^2$$

where

$$t_i^{th}(R_{fit}) = \mid \vec{R_{fit}} \mid /\beta(K_L^o)c + \mid \vec{Ap^i} - \vec{R_{fit}} \mid /c$$

in which the conversion apices of the photons are given by the vectors $\vec{Ap^i}$. The vertex radial resolution obtained, shown in Fig.1, has small overall σ, but a prominent

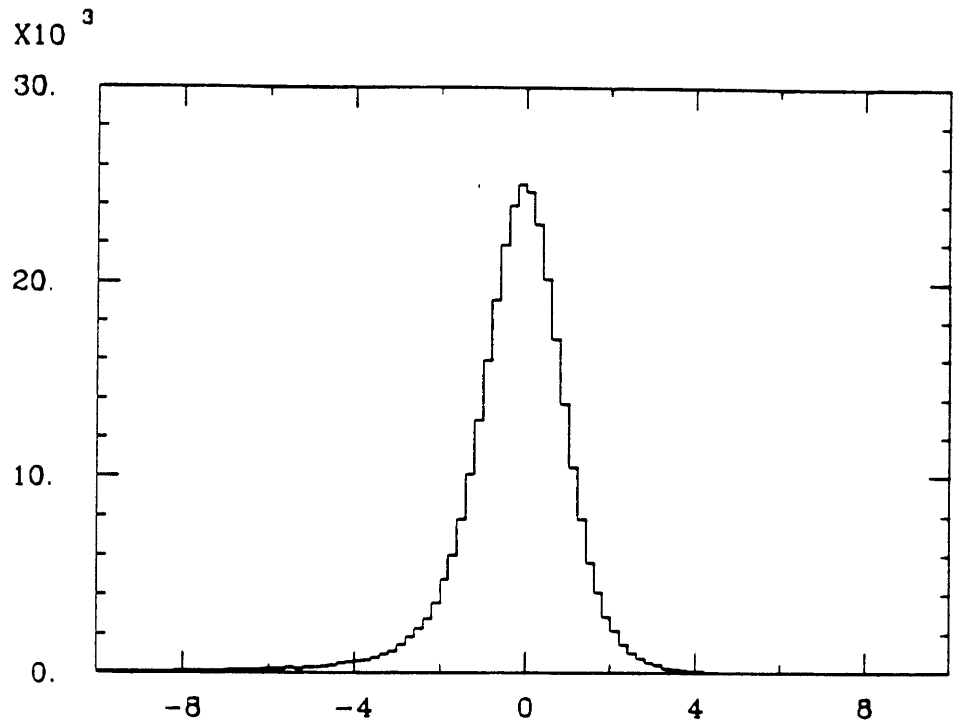

Fig.1: Vertex radial resolution, $R_{true} - R_{fit}$ (cm)

asymmetric tail, brought in by slower-than-nominal K_L^o 's produced by photon radiation from the initial state. The only important parameter appears to be the TOF resolution, assumed equal to 200 ps in Fig.1, independent of photon energy. A few observations are in order:

• Without kinematic constraints, the resolution is driven by the length of the K_L^o flight, due to $\beta(K_L^o)\cong 0.218$. So the fit is not particularly sensitive to the precise direction of the K_L^o flight and, by the same token, would *not* be able to determine it too precisely, should one leave it free to be fitted together with R_{fit}.

• This argument also implies that the exact location of photon conversion apices (assumed in this "fast" MC to be at entry of the calorimeter) and the resolution on them ($\sim$ 1 cm) are not much relevant to the vertex measurement. Both this point and the preceding one are nicely confirmed by the simulation.

• This fit offers *no* background rejection against $K^o_L \rightarrow \pi^o\pi^o\pi^o$ events, as the 4 found photons *do* come from a common vertex. It can be used, though, to get precise knowledge of the vertex resolution function from the $K^o_L \rightarrow \pi^o\pi^o\pi^o$ abundant statistics, to be used in the analysis of $K^o_L \rightarrow \pi^o\pi^o$ events (provision made for the different photon spectra, which could give different TOF resolutions). Varying the assumed TOF resolution, one gets the overall (tail-comprehensive) standard deviations shown in Tab.1:

	TOF resolution (ps)		
r range (cm)	200	300	400
0-20	7.5	10.6	13.9
20-40	9.2	11.9	14.9
40-60	11.0	13.3	16.0
60-80	12.7	14.7	17.1
80-100	14.4	16.2	18.5
100-120	16.2	17.8	19.9
120-140	17.7	19.2	21.2
140-160	19.2	20.5	22.3

Table 1: Vertex resolutions (in mm) for different radial ranges and time-of-flight resolutions.

Tab.1 also shows the *σ broadening*, coming in because of K^o_L slowness and finite beam energy spread (at DAFNE $\sigma_E \cong 500$ KeV), which causes $\beta(K^o_L)$ to take on values spreading 1.3% out from the nominal value. In other words the fit *compensates* for a $\beta(K^o_L)$ smaller (larger) than nominal by choosing a longer (shorter) R_{fit}, and the β spread effect is amplified by longer K^o_L decay lengths. The same also applies, of course, to the radiative tail.

The Montecarlo prediction for the smearing losses, $\Delta N/N = -1.7 \cdot 10^{-3}$ *has a minus sign* due to the asymmetry of the tail, and is bigger than the naive expectation by two orders of magnitude, clearly posing a potential problem, to be addressed either via an attempt to include into the fit the energy of the radiated photon, or via an accurate study of the resolution function using $K^o_L \rightarrow \pi^o\pi^o\pi^o$ events with 4 photons and subtraction of the radiative contribution.

$K^o_L \rightarrow \pi^o\pi^o\pi^o$ background removal

The task of removal of $K^o_L \rightarrow \pi^o\pi^o\pi^o$ events can be fully appreciated by noting that the $K^o_L \rightarrow \pi^o\pi^o\pi^o$ rate is 200 times bigger than the $K^o_L \rightarrow \pi^o\pi^o$ signal. Taking the "double ratio" method for a benchmark it is easily seen that, defining Δ to be the error on the estimated background, one must have

$$\Delta \cdot \frac{\varepsilon_{3\pi^o}}{\varepsilon_{2\pi^o}} \ll \frac{1}{\sqrt{N_{2\pi^o}}} \cdot \frac{B.R.(K^o_L \rightarrow 2\pi^o)}{B.R.(K^o_L \rightarrow 3\pi^o)}$$

in order that the error on the subtraction be negligible in comparison to the statistical error. This means that a knowledge of the background at the 10% level implies a rejection factor less than 10^{-5}.

The first criterium to achieve this will be simple photon-counting: given a combinatorial factor of 15, the probability for detecting only 4 photons out of 6 will be a fast-varying function of solid angle coverage *and* efficiency for low-energy photons to arrive without absorption or conversion to the calorimeter, and be detected there. This efficiency can only be obtained from a slow MC, but for the purpose of obtaining some insight, it has been simulated with a piecewise linear curve, rising from 50% at 20 MeV to a plateau value of 99% at 40 MeV. The covered solid angle (4π less two cones of half-aperture 8.5° around the beam axis) gives a geometric rejection factor of $0.5 \cdot 10^{-3}$, but the actual presence of quadrupoles *inside* the detector (not yet simulated) will reduce the solid angle seen by the K_L^o .

To gain additional rejection a kinematic fit has been used, which assumes known the event geometry from the preceding vertex fit, and recalculates the 4 photon energies imposing 3 constraints: conservation of energy and two π^o invariant masses. The good coupling of photons (out of the possible 3) is the one for which the final χ^2 is minimum. The $K_L^o \to \pi^o\pi^o\pi^o$ events will then populate a region with high χ^2 and $M(\pi^o\pi^o)$ smaller than 497 MeV/c. It is found that the resolution on the K_L^o mass is dominated by the calorimeter resolution $\sigma_E = const \cdot \sqrt{E}$, and does not depend much (through errors in photon directions)on vertex or conversion points resolution.

Tab.2 shows some results from the simulation:

σ_E(GeV)	$\varepsilon^{2\pi^o}_{\chi^2<10}$	$\varepsilon^{3\pi^o}_{\chi^2<10}$	σ_M(MeV)	$\varepsilon^{2\pi^o}_{M>490}$	$\varepsilon^{3\pi^o}_{M>490}$	$\varepsilon^{3\pi^o}_{90\%}$
$5\% \cdot \sqrt{E}$	0.923	0.010	3.4	0.893	$2 \cdot 10^{-3}$	$3 \cdot 10^{-3}$
$6\% \cdot \sqrt{E}$	0.918	0.028	3.9	0.869	$5 \cdot 10^{-3}$	$7 \cdot 10^{-3}$
$7\% \cdot \sqrt{E}$	0.910	0.057	4.5	0.840	$8 \cdot 10^{-3}$	$2 \cdot 10^{-2}$

Table 2: Signal and background efficiencies for different energy resolutions.

In the second and third column of Tab.2, the efficiencies for signal and background after the χ^2 cut are reported, normalized to the number of events with 4 photons. The fit rejection rate at this level range from 1% to 6%.

The resolution obtained for $M(K_L^o)$ is shown in the 4^{th} column, and the efficiencies after a lower cut at 490 MeV/c in the 5^{th} and 6^{th}. This cut is somewhat vexating on $K_L^o \to \pi^o\pi^o$ events for the "bad" resolution case, but the rejection rate stays just below the 1% mark, which would still suffice, should a more accurate simulation of photon absorption bring the rejection rate before fit up by a factor 2. In the last column, it has been tried to keep as many good events as possible at the expense of greater contamination, using a $M(K_L^o)$ cut which always keeps 90% of the $K_L^o \to \pi^o\pi^o$ events. This clearly poses harder constraints on the energy resolution of the calorimeter.

In conclusion, even if this analysis has to be put to the test of a better simulation, it already seems that the $K_L^o \to \pi^o\pi^o\pi^o$ background can be coped with, if only the photon detection efficiency can be kept high, and the energy resolution over the whole detector and energy range will reach these limits. More elaborate and precise fit techniques, which are currently being developed[†], will further improve on this. The problem of smearing losses needs more study, but the huge $K_L^o \to \pi^o\pi^o\pi^o$ statistic should allow for a complete understanding of the resolution curve of the detector, thus leaving room for optimism.

[†]see contribution by C. Bloise to these Proceedings