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Decay length reconstruction : $K^0_{s,l} \rightarrow \pi^0\pi^0$

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Abstract

The evaluation of the accuracy in reconstructing the K^0 neutral decay vertex is presented, assuming a calorimeter with good timing performances (σ_t $\approx$150 ps in the energy region of interest), besides reasonable energy and spatial resolution. The dependence on the K^0 time of flight is discussed. Results concern also the case in which one photon coming from π^0 decay escapes the detection.

1 CP violation parameters at DAΦNE

The possibility to determine $\frac{\epsilon'}{\epsilon}$ with a high luminosity machine running at the Φ peak has been extensively discussed, for example, in the proposal for a Φ factory at Frascati [1], where the contribution [2] is devoted to study the chain $\Phi \rightarrow K^0_S K^0_L \rightarrow \pi^+\pi^-\pi^0\pi^0$. Considering the process above, the degree of asymmetry of the differences in decay lengths between neutral and charged channels is related to the CP violation parameters, being three times the ratio $\frac{\epsilon'}{\epsilon}$.
The measurement accuracy is limited by the knowledge of the neutral decay vertex, that affects the precision achieved in selecting events inside the fiducial volume.
The $K^0 \rightarrow 2\pi^0$ decay length is measured starting from the energies and the impact points of photons coming from π^0 decay, requiring the momentum-energy conservation in the $\Phi \rightarrow K^0_S K^0_L$ process, besides the condition that invariant mass of γ pairs is equal to π^0 mass.
This work is intended to evaluate the vertex resolution achievable with a calorimeter measuring the photon arrival times, together with their impact points and energies. The assumptions made concern:

- accelerator machine energy spread : 300 keV;
- Φ localization (spread on the e^+ e^- interaction point): σ_x= 0.2 cm, σ_y= 20 μm, σ_z=3 cm;

- resolution on the momenta of charged pions: it has been parametrized as $\frac{\sigma(p_T)}{p_T} = 0.006$ (p_T in GeV) , $\sigma(tan\delta) = 0.005$, $\sigma(\phi) = \frac{3\cdot 10^{-4}}{p_\pi(GeV)}$, where p_T is the pion transverse momentum, δ is the angle with the beam axis and ϕ is the angle in a plane orthogonal to the beam axis;
- calorimeter energy resolution : $\frac{\Delta E}{E} = \frac{0.07}{\sqrt{E}}$ (E in GeV);
- calorimeter spatial resolution : $\sigma_x = \sigma_y = 1$ cm , $\sigma_z = 5$ cm;
- calorimeter timing performance : $\sigma_t = \frac{A}{\sqrt{E}}$, where the constant A has been chosen to get $\sigma_t = 300$ ps for photons with energy around 20 MeV.

These assumptions have to be thought as parametrizations of a reasonable experimental environment. To clarify their strength, and to allow simple comparison with full Monte Carlo simulations of different experimental set-ups, it is important to mention that the $\pi^0\pi^0$ invariant mass turns out to be equal to K^0 mass within 3 MeV, and that the flight direction is reconstructed with a precision of about 0.017 radians, if the four photons have been detected.

2 Results

The neutral vertex resolution depends on K^0 time of flight : the dependence is linear and the slope is a function of the energy spread of the accelerator machine (ΔE_A). In fact, the photon times are related to the K^0 time of flight approximately by $t \propto R_k \left(\frac{1}{\beta_k} - 1\right)$, and any uncertainty on β_k, the kaon velocity, affects vertex reconstruction: $\frac{\Delta R}{R} \approx \frac{\Delta\beta_k}{\beta_k(1-\beta_k)} \approx 6\ \Delta\beta_k$. The root mean square of the β_k distribution is about $2 \cdot 10^{-3}$, when the machine energy spread is 300 keV, and increases up to $3.5 \cdot 10^{-3}$ at $\Delta E_A = 500$ keV. Taking into account both, kinematical constraints and photon times, it has been found $\Delta R \approx \Delta R(0) + 5.5 \cdot 10^{-3} R$, by the comparison of the distribution widths obtained in three different regions of decay lengths. The energy spread affects also the knowledge of the kaon direction. In terms of kaon momentum, the uncertainty is of about 1 MeV in the beam direction, if $\Delta E_A = 300$ keV. The root mean square of the distribution of the reconstructed decay lengths, once the true value has been subtracted, is given by ΔR (cm) $\approx 0.45 + 5.5 \cdot 10^{-3} R$, e.g. less than 8 mm of uncertainty if the decay distance is less than 1 m. For comparison it is worth while mentioning that, if the timing performance of the calorimeter is assumed to be equal to 300 ps for any photon energy, vertex resolution is worsened of about 30% (fig. 1).
The calorimeter spatial resolution seems to affect slightly the decay length reconstruction: 10% improvement is achieved, changing the resolution from $\sigma_x = \sigma_y = 1$ cm, σ_z=5 cm to $\sigma_x = \sigma_y = \sigma_z = 1$ cm.
For each photon the time measured by the calorimeter allows to determine the K^0 decay distance independently from the other collected photons. Then, assuming that the photon with the minimum energy escapes the detection, the event reconstruction has been performed, obtaining the same decay length precision achieved in the case of events with four fully reconstructed photons . In fig. 2, the energy spectrum of the

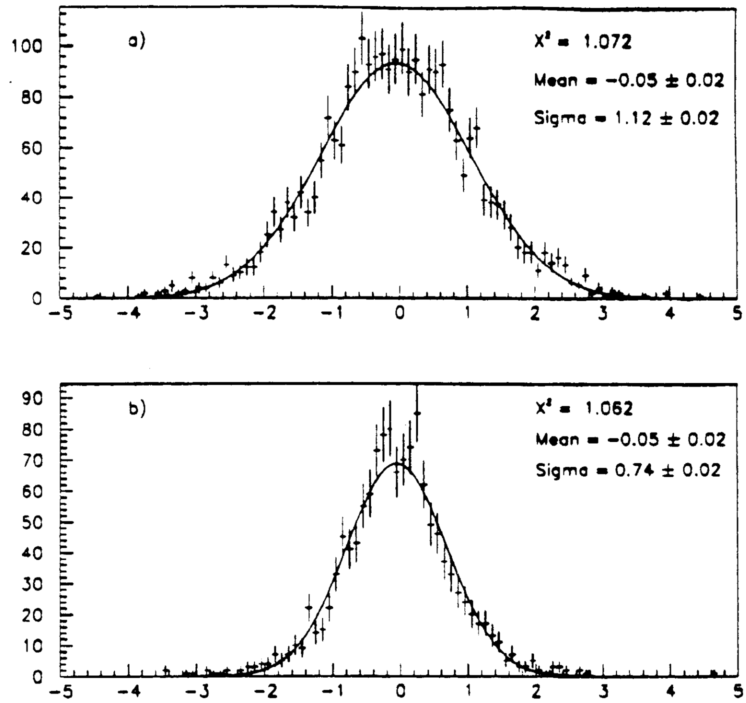

Figure 1: Differences between reconstructed and true values of decay length R(cm) for $K^0 \rightarrow \pi^0\pi^0$ events with $R < 100$ cm, assuming a calorimeter time resolution: a) $\sigma_t = 300$ ps, and b) σ_t (ps)= $45/\sqrt{E/GeV}$.

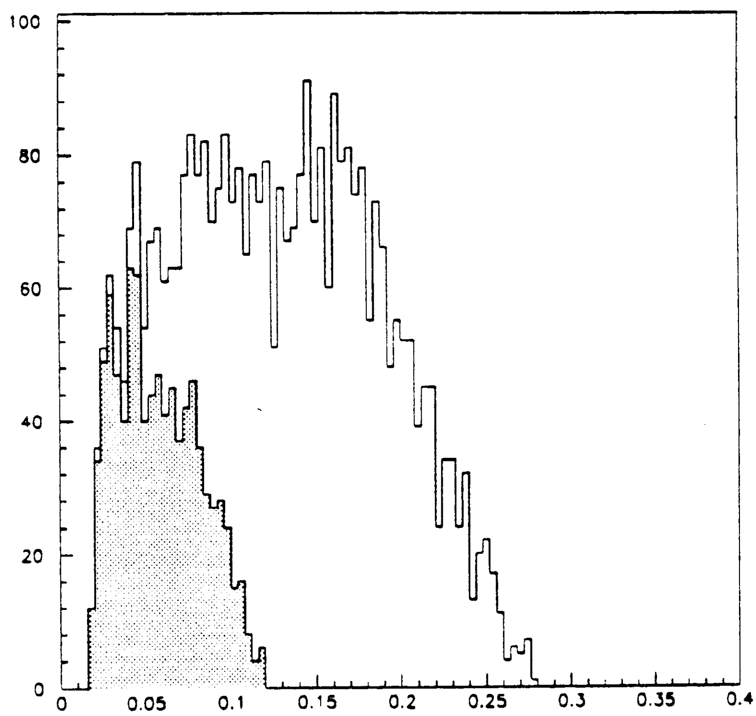

Figure 2: Energy spectrum of photons coming from π^0 decay, compared with (shaded region) the energy distribution of photons that have been supposed to escape the detection.

lost photons is shown and compared with the energy spectrum of the photons coming from π^0 decay.

3 Conclusions

A calorimeter with good timing performance provides a powerful tool to measure the K^0 neutral decay length using separately each photon coming from π^0 decay. The precision achieved is better than 8 mm, assuming a time resolution $\sigma_t \approx 150$ ps for the energies of interest (≈ 150 MeV) and for neutral decays occuring within 1 m from the interaction point. The result refers to the case in which the flight direction can be reconstructed within about 0.017 radians, taking into account both the machine energy spread and the resolution on the momenta of the charged pions.

Acknowledgements

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References

[1] *Proposal for a Φ Factory*, Nota Interna Laboratori Nazionali di Frascati - **LNF-90/031** ;

[2] G. Barbiellini and C. Santoni, *Proposal for a Φ Factory*, **LNF-90/031**, pag. 157; and also *A Study of Detector Parameters for a Φ Factory Experiment*, **CERN-PPE-90-124** (Sept. 1990).