KLOE at DAΦNE

the KLOE Collaboration

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INTRODUCTION

At the Frascati ϕ-factory DAΦNE [1] the kaon pairs are produced almost [1] back-to-back with a momentum of $\simeq$ 110 MeV/c, and with well defined quantum numbers, those of the photon. Because of these unique features of the ϕ-factory, the kaons can be efficiently tagged [2], and kaon quantum interferometry experiments can be performed.

The main physics motivation of the KLOE experiment is the measurement of the CP and CPT violation parameters from the classical method of the double ratio and from interferometry [2]. At full luminosity, $\mathcal{L}_o = 5 \times 10^{32}$ cm^{-2} s^{-1}, given that

1) Due the small crossing angle of the e^+e^- beams, 12.5 mrad, the ϕ mesons are produced with a momentum of $\simeq$ 13 MeV.
2) The observation of one kaon guarantees the existence of the other with determined direction and identity.

the cross section for $e^+e^- \rightarrow \phi$ at the ϕ resonance peak is $\simeq 3.2\mu$b, about 1600 ϕ's will be produced per second. This will allow the measurement of $\Re e(\varepsilon'/\varepsilon)$ from the double ratio with a statistical error of $\simeq 10^{-4}$ in two years (assuming 1 year of 10^7 s) of data taking, while keeping the systematic error down to the same level.

THE KLOE DETECTOR

Concerning the CP studies in $\mathrm{K^o}$ decays, the main tasks of the KLOE detector are the control of the efficiencies for the decays of interest, and the rejection of the background from the copious $\mathrm{K_L}$ decays to states other than $\pi\pi$. The main components of the KLOE detector [3] [4] are the electromagnetic calorimeter (EmC) and the drift chamber (DC), both embedded in a magnetic field of 0.6 Tesla, generated by a superconducting solenoid.

The beam pipe at the interaction region is a 10 cm ($\simeq 16\lambda_S$) beryllium sphere 0.5 mm thick. This allows to define a fiducial volume for $\mathrm{K_S}$ without complications from regeneration and to minimize the multiple scattering and energy loss for charged particles.

Two low-beta quadrupole triplets are placed inside the inner cylinder of the DC, close to the interaction region. They are instrumented with lead-scintillator tile calorimeters to improve the photon acceptance. This will help the rejection of $\mathrm{K_L} \rightarrow 3\pi^o$.

THE ELECTROMAGNETIC CALORIMETER

The main tasks of the KLOE EmC are the measurement of the kaon neutral vertices with a resolution of $\simeq$ 1 cm, and the rejection of the background due to the $3\pi^o$ mode. To reach these purposes the EmC has to provide good energy resolution, excellent timing performance, good resolution for the γ apices measurements, high efficiency for the detection of low energy γ (down to 20 MeV), and hermetic coverage. The KLOE EmC is a very fine sampling lead/scintillating fiber calorimeter. The composite (lead:fiber:glue) of the modules has a density of $\simeq$ 5 gr/cm^3 resulting to a sampling fraction of $\simeq 13\%$ for a minimum ionizing particle. The barrel is a cylinder of 4 m inner diameter, made of 24 modules with fibers running parallel to the beam line. The end-caps are made of 32 C shaped modules of variable length with fibers running perpendicular to the beam line. The total acceptance is 98% of the full solid angle. The modules are read-out at both ends by photomultipliers. The read-out granularity is 4.4×4.4 cm^2 varying slowly in size across the modules. The spatial resolution in reconstructing the e.m. shower apices is $\sim$ 1.2 cm, and $\sim$ 2.5 cm along the direction of the fibers as obtained by time difference. The energy calibration is done equalizing the response of the photomultipliers with MIPs and deducing the energy scale with Bhabha and $\gamma\gamma$ events.

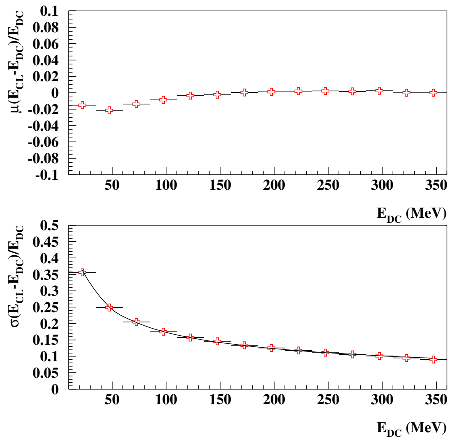

FIGURE 1. The non-linearity in the energy response (up). The measured EmC energy resolution ($\sigma_E/E \simeq 5.7\%/\sqrt{E(GeV)}$) (down).

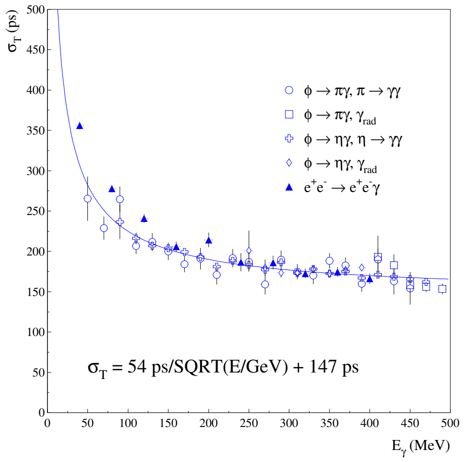

FIGURE 2. The measured EmC time resolution ($\sigma_t \simeq 54$ ps$/\sqrt{E(GeV)} + 147$ ps).

The energy resolution curve has been obtained using $\phi \rightarrow \pi^+\pi^-\pi^o$ events and it is in fine agreement with the design request ($\sigma_E/E \simeq 5.\%/\sqrt{E(GeV)}$). The non-linearity of the energy response is within $\sim 1\%$ over the entire energy range of interest (fig. 1). After time equalization with MIPs, the time resolution as a function of the energy is deduced from the ϕ radiative decays and Bhabha radiative decays (fig. 2). Such a good timing performance allows to measure the flight path of the $\mathrm{K_L} \rightarrow$neutrals, thanks to the method illustrated in figure 3.

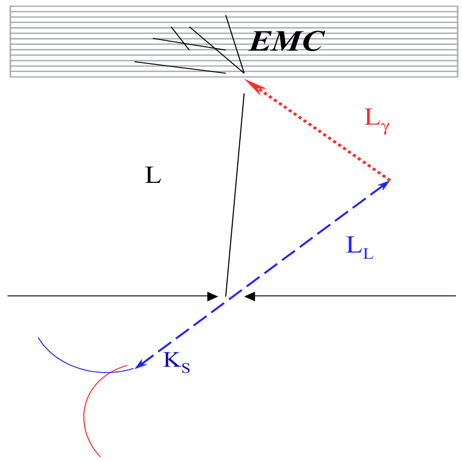

FIGURE 3. Neutral vertex position measurement: L is deduced from the γ conversion point, L_K is deduced from the direction of $\mathrm{K_S}$ that decays in $\pi^+\pi^-$. In addition the γ arrival time is measured and β_{K_L} is known.

THE DRIFT CHAMBER

Because of the decay length of the K_L ($\lambda_L \simeq 340$ cm), to maximize the fiducial volume for the charged decay detection, the chosen radius of the DC is 2 m. The K_L decay vertices are uniformly distributed in the tracking volume, and to obtain high and uniform track and vertex reconstruction efficiency the wires are in all-stereo configuration, in order to have an uniform filling of the chamber with almost square cells. The stereo angles varies with radius from 50 to 120 mrad going outward, and the dimension of the cells are $\simeq 2 \times 2$ cm^2 for the first 12 layers and $\simeq 3 \times 3$ cm^2 for the outer 46 layers. Because of the low momenta of the particles (between 50 and 300 MeV/c) a helium based gas mixture has been chosen to minimize the multiple scattering: $90\%He - 10\%iC_4H_{10}$ for a total radiation length of ~ 900 m, including $\simeq 52000$ wires. The KLOE DC needs all its walls to be very thin in order for them to be almost transparent to γ's from π^o decays to be detected in the calorimeter. The whole mechanical structure is made of carbon-fiber/epoxy $\simeq 8$ mm thick, for a total material ≤ 0.1 X$_o$.

The time response of the KLOE DC is fully calibrated using cosmic ray events. The spatial resolution in the r, ϕ plane is $\leq 150\mu$m over a large part of the cell. The hit efficiency is $\geq 99\%$. The efficiency for associating an hit to a track is $\simeq 97\%$. The measured momentum resolution, obtained using Bhabha events, agrees with the expected value $\sigma_{p_\perp}/p_\perp \simeq 0.3\%$ (fig. 4). The good DC performance is also shown by the invariant mass resolution for $K_S \to \pi^+\pi^-$, $\sigma \simeq 1$ MeV/c^2 (see fig. 5).

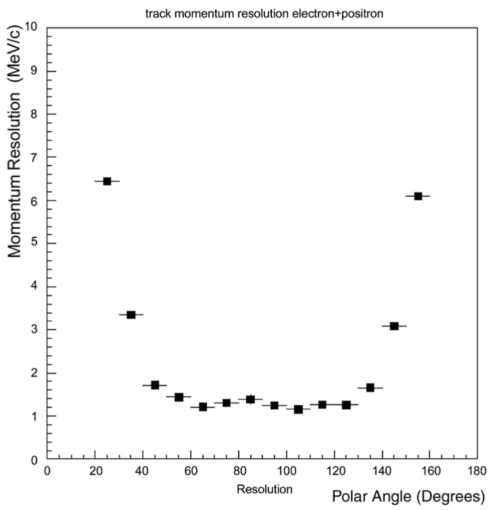

FIGURE 4. $\sigma_{p_\perp}/p_\perp$ against the polar angle.

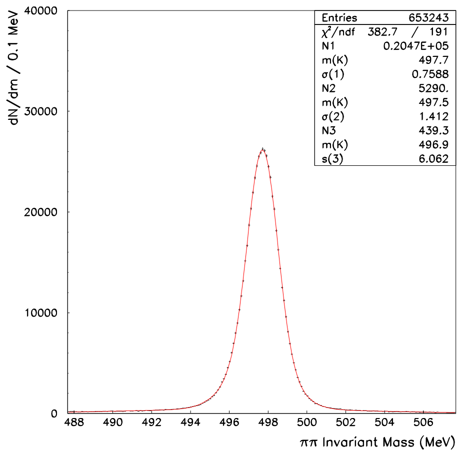

FIGURE 5. Invariant mass for $K_S \to \pi^+\pi^-$.

TRIGGER AND DAQ

The KLOE trigger [5] is designed to have an inefficiency $few \times 10^{-3}$ on CP violation decays and to reject/down-scale to few KHz the Bhabha events ($\sim$ 20 KHz), cosmic rays and machine background ($\sim$ 3 KHz). The bunch crossing occurs at DAΦNE every 2.7 ns and thus the KLOE trigger must operate in continuous mode. The KLOE trigger is a two level trigger. The *fast trigger* T1 (about 200 ns after the ϕ) is synchronized with the DAΦNE clock and provides the start to the digitizing electronics of the EmC. The *validation trigger* T2 (1.5 μs after T1) provides the stop to the TDCs of the DC (allowing for drift time) and the start to the Data Acquisition system. T1 and T2 triggers are based on the topology and energy deposits in the EmC and/or on the number and distribution of the DC hits. The final trigger configuration is fully operational and the study of its performance is in progress.

The Data Acquisition (DAQ) system [6] has to handle $\simeq$ 23000 FEE channels on a $\sim$ 5 KHz data rate, half due to the ϕ decays and half due to properly scaled down Bhabha and cosmic rays events. The signal digitization occurs in 2μs, and the bandwidth is 50 MByte/s (at 5 KByte/event). The system has been operated successfully up to more than 24 hours continuous running.

FIRST DATA TAKING OF KLOE AT DAΦNE

The grand total of the events has been collected mainly in November and December 99 ($\mathcal{L} \simeq 3.5 \times 10^{30}$ cm^{-2} s^{-1}) and correspond to an integrated luminosity of 2.4 pb^{-1}, about 8 millions of ϕ decays. The events collected has been used to fully calibrate and to study the main performances of KLOE in detecting the K mesons decays. Here are reported few results related with the K_L and K_S tagging procedures.

The K_L can be tagged identifying the $K_S \to \pi^+\pi^-$ events, looking for charged vertecies with 2 tracks of opposite sign reconstructed inside a cylinder ($r \leq 6$ cm and $|z| \leq 8$ cm) around the interaction region, and invariant mass between 400 and 600 MeV/c^2. The K_L tag efficiency looking for $K_S \to \pi^+\pi^-$ events is $\simeq 50\%$. The background contamination is less than 1%, and is mainly due to $\phi \to K^+K^-$ events. The $K_S \to \pi^+\pi^-$ sample has been used to evaluate the K_S lifetime: $\lambda_S = 5.70 \pm 0.05 \pm 0.03$ mm.

The excellent time resolution is used to tag the K_S looking for K_L 's interacting in the calorimeter (K_L crash) by measuring their speed. The selection looks for one neutral cluster with speed $0.195 \leq \beta \leq 0.245$, and energy $E_{cluster} \geq 100$ MeV. The K_S tag efficiency looking for K_L crash is $\simeq 30\%$, and the background contamination, mainly due to machine background and cosmic μ's, is $\sim 15\%$.

The figure 6 shows the plot of the square of the missing invariant mass in the $\pi\pi$ hypothesis, against the missing momentum of the charged track pairs coming from the K_L vertecies [3]. Thanks to the good momentum resolution of the KLOE DC, the three main K_L charged decay modes are nicely separated. Applying a very loose cut, $P_{miss} \leq 10$ MeV/c and $|M|^2_{\rm miss} \leq (70$ MeV/c$^2)^2$, the first CP violating events distributed on a narrow peak (494.9 ± 2.5 MeV/c^2) has been identified (fig. 7).

[3] The K_L momentum and direction are given by the reconstruction of the $K_S \to \pi^+\pi^-$ events.

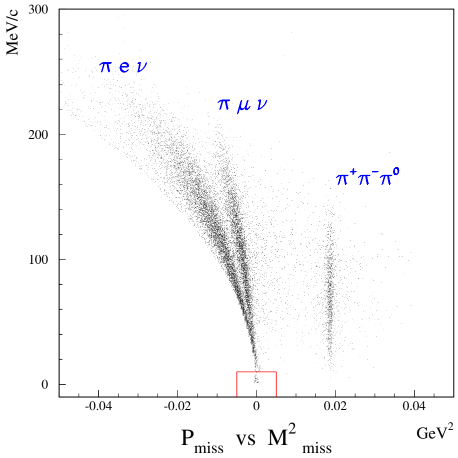

FIGURE 6. K_L charged decay modes in the kinematic plane. The small box defines the CP violation region of interest.

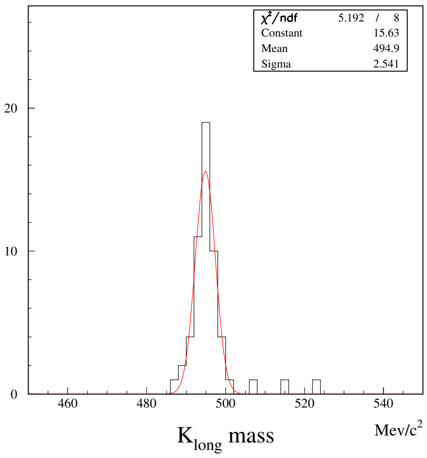

FIGURE 7. Mass distribution of the selected $K_L \to \pi^+\pi^-$ events.

CONCLUSION

The KLOE experiment at the Frascati ϕ-factory DAΦNE has collected $\simeq 2.4$ pb^{-1} of integrated luminosity. These data has been used to study the detector performances in reconstructing the kaon decays, as introduced here and more in detail in [7], and also to produce the first physical results concerning the radiative decays of the ϕ's [8].

The main physics item of the KLOE experiment is the measurement of the CP and CPT violation parameters in the kaon system. However an initial luminosity of $\mathcal{L} \simeq 10^{31}$ cm^{-2}s^{-1} will permit to collect in 1 year of running, enough data to study the structure functions of the weak and e.m. kaon decays (still unknown or contradictory like in $K_{\mu 3}$), and to perform tests of the Chiral Perturbation Theory.

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