Status Report for the KLOE experiment at DAΦNE

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The KLOE experiment's major physics goal is to measure the $\Re(\epsilon'/\epsilon)$, with a precision of 10^{-4}, via both the traditional double ratio method and the kaons' quantum interferometry. The experiment has started taking data at DAΦNE, the ϕ-factory at the Frascati National Laboratory (LNF) of INFN in Italy, beginning in April 1999. Integrated luminosity exceeding 100 pb^{-1} (10^8 ϕ's) are expected to be delivered for end 1999/early 2000. A description of the detector's design and of its performances is presented. At the moment of writing the experiment has collected its first collisions for an integrated luminosity of 220 nb^{-1}; the peak luminosity reached has been of $2 \times 10^{30} cm^{-2} sec^{-1}$.

1. Introduction

The Frascati ϕ factory, DAΦNE[1], is an e^+e^- collider optimized to operate at center of mass energy of M_ϕ with very high luminosity ($L_{peak} = 5 \times 10^{32} cm^{-2} sec^{-1}$). The vector meson ϕ decays into K^+K^- 49 %, $K_S K_L$ 34 %, $\rho\pi$ 13 % and $\eta\gamma$ 1.3 % of the time. Thus DAΦNE can be considered a factory of neutral and charged kaons. The neutral kaons are produced in collinear pairs, with momenta of $\sim$ 110 MeV/c and in a pure quantum state ($J^{PC} = 1^{--}$), the same as that of the ϕ meson. Quantum interferometry effects exist between the pairs of produced $K_S K_L$ allowing the measurement of most of the CP and CPT violation parameters. This clean $K_S K_L$ system also allows for efficient tagging; the observation of one kaon guarantees the existence of the other one with determined direction and identity. A pure K_S beam *without using any regenerator* is therefore available. At design luminosity DAΦNE will produce, in one HEP physics year (10^7 sec), 8.5×10^9 $K_S K_L$, 1.2×10^{11} K^+K^-, 2.5×10^8 η, 2.5×10^6 η' and $\sim 10^5$ a_o, f_o.

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The physics goals are: (1) the measurement of CP/CPT parameters from interferometry and double ratio; (2) the measurement of the kaons' form factors, the K_S rare decay and the K_S semileptonic asymmetry (never measured); (3) on the radiative ϕ decays [7] both an investigation of the a_o, f_o nature and a precise determination of the relative branching ratio between $\phi \to \eta\gamma$ and $\phi \to \eta'\gamma$. With the first 100 pb^{-1} we expect to measure $\Re(\epsilon'/\epsilon)$ with an error of $\sim 0.1\%$, to improve the measurement of the kaon form factors and to carry out most of the program described in item (3).

The double ratio (R) is related to $\Re(\epsilon'/\epsilon)$ as follows:

$$R = \frac{N(K_L \to \pi^+\pi^-)/N(K_S \to \pi^+\pi^-)}{N(K_L \to \pi^o\pi^o)/N(K_L \to \pi^o\pi^o)} = 1 + 6\Re(\epsilon'/\epsilon) \qquad (1)$$

the final goal of the experiment is to measure $\Re(\epsilon'/\epsilon)$ with a precision of 10^{-4} which translates into an error on R of few 10^{-4}. From the experimental point of view the production rate of the kaon pairs and the tagging efficiency for the K_S and the K_L cancel out identically in the double ratio. The main backgrounds are $K_L \to \pi^0\pi^0\pi^0$ (K_L^{000}) and $K_L \to \pi\mu\nu$ ($K_{\mu 3}$) which have signal to noise ratios of 1/240 and 1/135 respectivelly; rejection factors of $8(6) \times 10^{-4}$ are needed. The determination of the various efficiencies and their errors is another origin of systematics. Fortunately, KLOE is a self-calibrating experiment; the use of events such as $K_L \to \pi^+\pi^-\pi^0$ ($K_L^{\pi\pi\pi}$), which produce in the final state both charged and neutral pions, will allow one to determine the efficiencies from the data themselves. Furthermore, since the events' counting has to be performed in a specific fiducial volume, the determination of these volumes should be very accurate. At these energies the decay length (λ) of the K_S (K_L) is around 0.6 mm (345 cm); since all K_S's decay inside the beam pipe they do not contribute to this error. Instead, for K_L's the precision on the difference between the external boundaries of charged/neutral decays has to be known with a precision of ~ 0.5 mm. Usage of $K_L^{\pi\pi\pi}$ events will help in surveying and correcting for this difference.

2. DAΦNE and KLOE: the pilot run

Statistics is the other half of the game. In order to reach the desired accuracy in $\Re(\epsilon'/\epsilon)$ we need to collect $\sim 4 \times 10^6$ K_L^{00}. At peak luminosity two physics years will be enough to fulfill this task. In order to reach this level of luminosity, DAΦNE has been designed with a conservative single bunch luminosity ($L_0 \sim L_{VEPP-2M} = 4 \times 10^{30} cm^{-2} sec^{-1}$) and with a large number of bunches (up to 120). The DAΦNE complex consists of two coplanar rings (one for e^+, the other for e^-), a Linac ramping e^+ up to 550 MeV and e^- to 800 MeV and an accumulator ring of 510 MeV for fast topping-up. The peak beam energy is 510 MeV with a 0.4 MeV spread. The two beams ($\sigma_x, \sigma_y, \sigma_z = 20\ \mu m, 2\ mm, 3\ cm$) intersect with an angle of ~ 12 mrad to reduce parasitic interaction between ingoing and outgoing bunches. Crossing frequency is up to 368 MHz with 120 bunches circulating in the machine. Typical number of particles/bunch is $\sim 10^{11}$, corresponding to ~ 43 mA; total current per beam 5.2 A. Conservative values of the tune-shift (0.04), β_x, β_y coupling ($\sim 1\%$) and $\beta_y = 0.045\ m$ have been chosen.

Before KLOE rolled-in $L \sim 1.5 \times 10^{29} cm^{-2} sec^{-1}$ was achieved in single bunch mode with 20 mA/beam. In multi-bunch mode $L \sim 10^{31} cm^{-2} sec^{-1}$ with 13 bunches and ~ 200 mA/beam was also reached. The KLOE insertion introduced a large perturba-

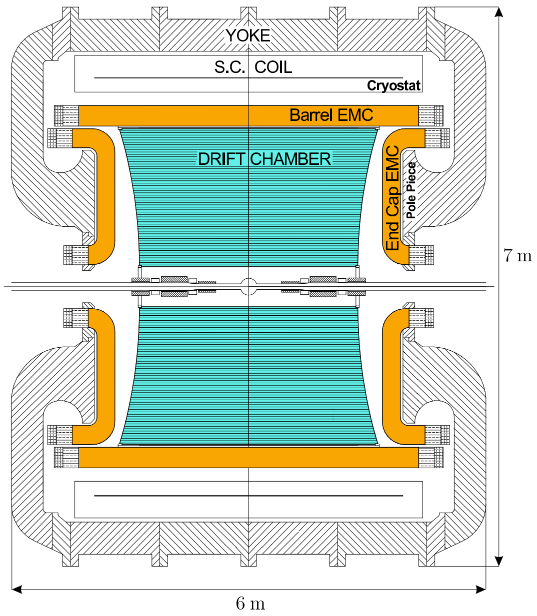

Figure 1. Schematic view of the KLOE detector

tion in the ring(s) optics and, although a first order compensation has been achieved, the e^- (3%) coupling has not yet reached the design value. At the moment of writing a $L_0 \sim 2 \times 10^{29} cm^{-2} sec^{-1}$ with 10 mA/bunch and $L \sim 2 \times 10^{30} cm^{-2} sec^{-1}$ with ten bunches have been reached.

The KLOE detector was fully operational since July 1998 and a lot of experience on the detector calibration, data acquisition and triggering has been gained running with cosmic rays on the apparatus. The detector rolled-in in March 1999 and the first collisions were observed and recorded on the 23rd April 1999. Another few weeks were later dedicated to the study of the ϕ line shape running in single bunch mode. Once the beam energy was determined multi-bunch operation started. Up to now we had only 10 days of stable operation during August. The integrated luminosity of this pilot run was $\sim$ 200 nb^{-1} which allowed us to tune-up the calibration and reconstruction procedures.

3. Overview of KLOE and its performances

The KLOE detector [2] [3] is a general purpose e^+e^- detector of respectable dimension ($\sim$ 5 m diameter, 4 m length). Going outward (fig.1) a 0.5 mm cylindrical beryllium beam pipe with a spherical shape of 5 cm radius (16 λ_s) surrounds the interaction point. The permanent inner quadrupoles region is instrumented by two lead-scintillator tiles calorimeters of $\sim$ 5 cm thickness organized in 16 wedges. Its major physics goal is to improve the rejection efficiency for K_L^{000}. Altough the reduced shower containement results in a poor energy resolution, the timing and position performances ($\sigma_x \sim 5\ cm$, $\sigma_t \sim 1\ ns$) are enough to achieve the desired rejection power. A large drift chamber, DCH [4], of 3 m diameter and 4 m length, follows surrounded by an electromagnetic calorimeter, EmC, which covers almost hermetically the solid angle. Everything is embedded inside a cryostat and a specially shaped iron yoke. The superconducting coil generates a B field of 6 KG. The trigger [6] and data acquisition, DAQ [5], systems allow us to handle the high event rate. At the highest luminosity we expect to have $\sim$ 2.5 KHz of ϕ, $\sim$ 50KHz bhabha, 2.5 KHz cosmics and few KHz of machine background. Our DAQ is able to handle a data throughput up to 50 MB/sec through two levels of data concentration via dedicated hardware processors and online event building in parallel farms. The two levels trigger is based on EMC energy deposit and DCH hit multiplicity. Its main task is to reduce the event rate to the one allowed by DAQ without "loosing" any relevant ϕ decay while retaining some portions of bhabha and cosmics for calibration purposes.

The main task of the EmC is to reconstruct the K_L^{00} decay and to efficiently reject the K_L^{000} background. At KLOE the vertex reconstruction of the decay $K_{S,L} \to \pi^0\pi^0$ is performed by accurately measuring the arrival time to the calorimeter of even a single photon [2,3]. These requirements correspond to the following design specifications: (1) $\sigma_E/E \sim 5\%/\sqrt{E\ (\mathrm{GeV})}$; (2) σ_T better than 70 ps$/\sqrt{E\ (\mathrm{GeV})}$; (3) full efficiency for γ's in the range 20–280 MeV; (4) hermeticity.

The KLOE EmC is a fine sampling lead-scintillating fiber calorimeter with photomultiplier (PM) read-out. The central part (barrel) approximating a cylindrical shell of 4 m inner diameter, 4.3 m active length and 23 cm thickness ($\sim$ 15 X_0), consists of 24 modules. Two end-caps, consisting of 32 "C" shaped modules, close hermetically the barrel. The modules are read out on the two sides with a granularity of$\sim$ 4.4×4.4 cm^2 by fine mesh PM's for a total number of 4880 channels.

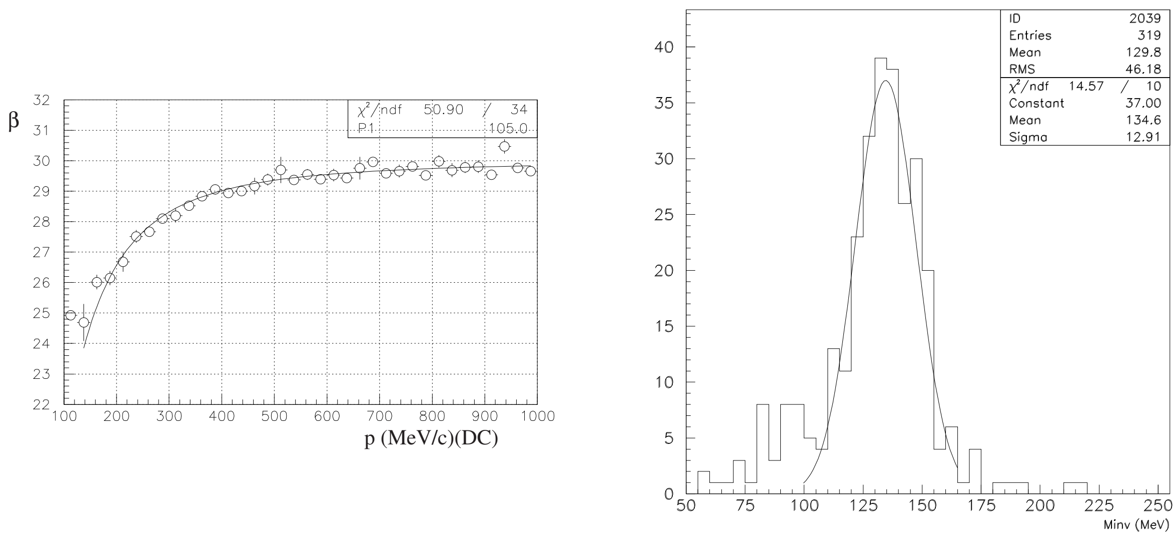

Figure 2. EMC performances: a) $c\beta$ vs P(Mev/C) for cosmic ray events, the fit is described in the text; b) Invariant mass of the two γ's coming from π^0 in $\pi^+\pi^-\pi^0$ events.

The basic calorimeter structure consists in an alternating stack of 1 mm scintillating fiber layers glued between thin grooved lead foils. The final composite has a fiber:lead:glue volume ratio of approximately 48:42:10, a density of $\sim$ 5 g/cm^3 and a radiation length X_0 of $\sim$ 1.6 cm. The EmC modules and the front-end electronics were fully installed in KLOE at the beginning of 1998. The calorimeter has been fully operational since then. After the installation, a first calibration of the calorimeter with cosmic rays has been performed to obtain the minimum ionizing peak for each calorimeter channels with an accuracy better than 1%. The responses of all PMs were then equalized within few percent. The times measured at the two ends of a cell allow us to obtain the arrival

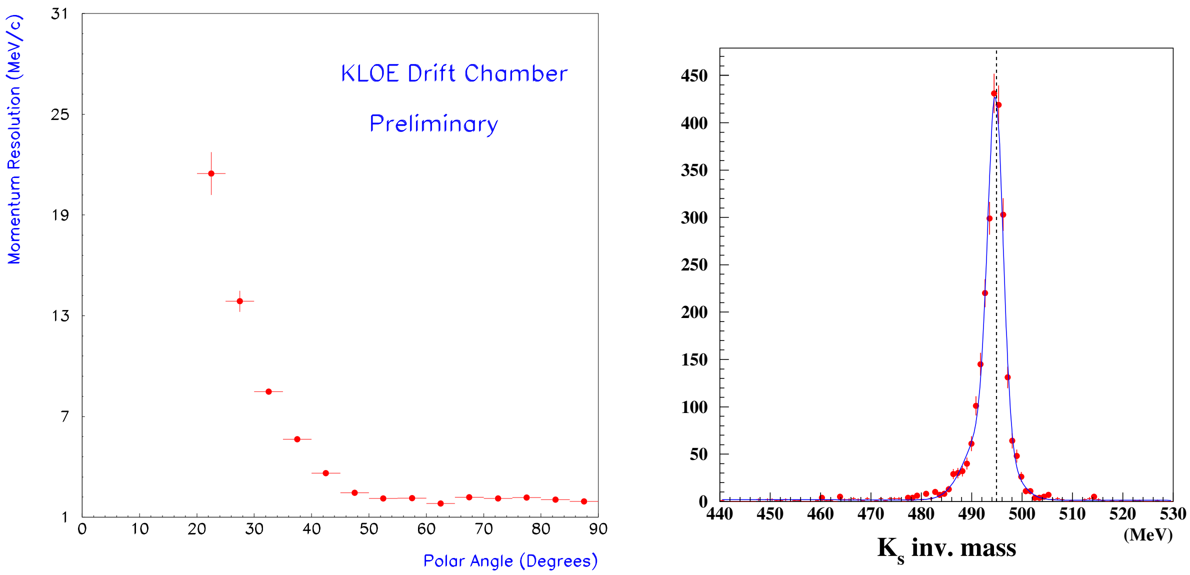

Figure 3. DCH performances: a) $\sigma/$P as function of θ angle for bhabha events, b) invariant mass of the $\pi^+\pi^-$ coming from K_S decays.

time of the particles and the coordinate along the fiber. Assuming "c"-speed and fitting the measured time pattern for the fired cells in straight cosmic ray events, the time offset of each channel is determined with a precision of $\sim$ 10 ps. A check of this calibration consists in measuring the velocity of cosmic rays as a function of track momentum. A fit to the measured distribution with the relativistic velocity $c\beta = cp/\sqrt{p^2+m^2}$, leaving the mass m as the only free parameter, provides a value in good agreement with the muon mass, as shown in fig.2-right.

The bhabha and $e^+e^- \rightarrow \gamma\gamma$ events allow us then to set the energy and time scales. The energy resolution obtained is $\sim$ 7.8 % corresponding to $\sigma/E \simeq 5.5\%/\sqrt{E(\mathrm{GeV})}$. As a check of the energy scale calibration we reconstructed the invariant mass of the photon pair from $\phi \rightarrow \pi^+\pi^-\pi^0$ events. The peak in the invariant mass distribution is within 1 MeV from the π^0 mass, as shown in fig.2-left. Another independent check comes from the reconstruction of $\phi \rightarrow \eta(\pi^0)\gamma \rightarrow \gamma\gamma\gamma$ events reported in ref. [7]. In order to evaluate the time performances of the calorimeter, the quantity $\Delta t = t_{clu1} - R_1/c - t_{clu2} - R_2/c$ is measured for the two photons of $e^+e^- \rightarrow \gamma\gamma$ events; t_{clu} is the arrival time of the particle as measured by the calorimeter cluster, R is the position of the cluster centroid. We observe $\sigma_{\Delta T} \sim 150$ ps corresponding to $\sigma_t \sim 75$ ps$/\sqrt{E\ (\mathrm{GeV})}$;

The DCH should provide 3-D tracking with a resolution of $\sim$ 200 μm in the bending plane and a z-resolution of $\sim$ 1 mm on decay vertex over the whole sensitive volume. In order to efficiently reject the $K_{\mu 3}$ background a momentum resolution of 0.5% for low momentum tracks is required; the active volume should be as trasparent as possible to minimize multiple scattering. Since the K_L's decay almost uniformly all over the whole chamber, the tracking reconstruction efficiency should have minimal dependence on the position in the DCH. The design of the tracker is also driven by the requirement of having a light and homogeneous active volume to prevent K_L regeneration and photon conversions; for the same reason low-mass walls are necessary. The adopted solution is a cylindrical drift chamber whose supporting structure is entirely made of carbon-fiber and filled with an ultra-light gas mixture (90% He-10%iC_4H_{10}). The requirement of a 3-D reconstruction and of uniform tracking forces the choice of square cells arranged in layers with alternated stereo angles. In order to keep a constant drop the stereo angles varies with increasing radius from $\pm$60 mrad to $\pm$ 150 mrad. The cells are organized in 12 inner layers of smaller cells ($2 \times 2\ cm^2$) and 46 outer layers of bigger cells ($3 \times 3\ cm^2$). Good efficiency and space resolution, together with negligeable ageing effects, are obtained running at a gas gain of $\sim 10^5$. This requirement is met with 25 μm W(Au) sense wires and 80 μm field Al(Ag) wires kept at d.d.p. of $\sim$ 1.9 KV. The DCH has a grand total of 52000 wires with a ratio 3:1 between the number of field to sense wires. The DCH was moved inside KLOE on April 1998 and has been kept in operation for more than 1 year with a very low number of dead/hot channels/wires (below 0.1%).

The calibration of the drift chamber proceeds, after subtracting the time offsets of each single wire, via an iterative procedure which minimizes the fit residuals by redefining the s-t relations. In this gas mixture we do not expect to have a saturated drift velocity since it depends on, at least, the sixth power of the drift distance (Drd). The s-t relations are therefore not linear and they are parametrized with a 5th order Chebychev polyomial. The procedure stops whenever the mean of the fit residuals is below 100 μm. The behaviour of the space resolution along Drd shows the usual dependence on primary ionization and longitudinal diffusion. The value of the resolution averaged along Drd is $\sim$ 150 μm. Using cosmics the whole chamber calibration takes $\sim$ 4 hours.

Using bhabha and $K_s \to \pi^+\pi^-$ we can then evaluate the momentum resolution and the momentum scale. As shown in fig.3-left we obtain a momentum resolution better than 0.4% for polar angle greater than 45°. The invariant mass of the K_S is also reported in fig.3-right; fitting it with a gaussian we obtain $M_{K_s} \sim$ 496 MeV with σ of $\sim$ 1 MeV.

4. CONCLUSIONS

KLOE and DAΦNE have started their activity. DAΦNE is deliverying L of $\sim 2 \times 10^{30} cm^{-2} sec^{-1}$ with average values of $\sim$ 90 nb^{-1} per day. The KLOE detector is fully operational. At the end of this first run we expect, in early 2000, to collect 100 pb^{-1} (1/100 of the full statistics) to begin our physics program.

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