PROCEEDINGS OF SCIENCE

The KLOE-2 experiment at DAΦNE upgraded in luminosity

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The KLOE experiment at the DAΦNE e^+e^- collider of the Frascati Laboratories of INFN is going to start a second data-taking campaign (KLOE-2). The detector has been upgraded with small angle electron taggers; the insertion near the interaction point of an inner tracker and a couple of calorimeters at low angle (QCALT and CCALT) is planned for the next year. The interaction region of DAΦNE has been modified using a crabbed waist scheme, which has been successfully tested during year 2008. An improvement in luminosity of about a factor of 3 is expected. The KLOE-2 scientific program aims to further improve the experimental studies on kaon and low energy hadron physics, e.g. CKM unitarity and Lepton universality, CPT symmetry and quantum mechanics, low energy QCD, gamma-gamma physics and the contribution of the hadron vacuum polarization to the muon anomalous magnetic moment.

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Introduction

The KLOE experiment has collected 2.5 fb^{-1} of data at the $\phi(1020)$ meson peak and 250 pb^{-1} off-peak ($\sqrt{s} = 1$ GeV) at DAΦNE, the e^+e^- collider of INFN Laboratori Nazionali di Frascati during the 2001-2006 data-taking campaign. Many important results have been obtained in kaon and hadron physics: the measurement of all branching ratios of K_S, K_L and $K^{\pm}$, the study of scalar and pseudoscalar mesons, the measurement of $e^+e^- \to \pi^+\pi^-(\gamma)$ cross section from which most of the dipion hadronic contribution to the muon anomaly can be derived. During 2008 a new interaction scheme for DAΦNE has been implemented and tested, allowing to reach a peak luminosity of 4.5×10^{32} cm^{-2} s^{-1}, a factor of 3 larger than the previous achievement. The new scheme has a larger crossing angle, a reduced beam size at the interaction point (IP) and the presence of a pair of crab-waist sextupoles. With this new configuration ~ 5 fb^{-1}/y can be delivered thus offering a powerful tool for the proposed new physics program.

The KLOE-2 program includes not only improvements on KLOE measurements but also new physics topics as [1]: study of $\gamma\gamma$-physics based on sample tagged by new detectors, the search for particles from "hidden sectors" that might explain dark matter, and a precise measurements of the hadronic cross section near the $\pi\pi$-threshold.

Detector Improvements

KLOE is a general purpose detector, mainly consisting of a large cylindrical drift chamber with 2 m radius, surrounded by a lead-scintillating fiber electromagnetic calorimeter. Both sub-detectors are immersed in the 0.52 T axial magnetic field of a superconducting coil. The detector was optimized for CP and CPT studies in the neutral kaon system, produced in the ϕ decay almost at rest. For the forthcoming data-taking, upgrades of the detector are foreseen. In a first phase, referred to as STEP-0, two new detectors, the Low Energy Tagger (LET) and the High Energy Tagger (HET), will be installed along the beam line to detect the scattered leptons from $\gamma\gamma$ interaction. In a second phase, named STEP-1, a light-material inner tracker (IT) will be installed in the region between the beam pipe and the drift chamber in order to improve the vertex reconstruction from charged tracks and to increase the acceptance of tracks with low-p_t. A new tile calorimeter (QCALT) will surround the focusing quadrupoles near the IP for the detection of photons coming from K_L decays in the drift chamber. A crystal calorimeter (CCALT) will cover the low θ region, attempting at increasing acceptance for very forward leptons/photons down to 8°. The expected integrated luminosity for the two phases is 5 fb^{-1} and 20 fb^{-1} respectively.

STEP-0 upgrades

The STEP-0 phase will start new data taking with the present KLOE detector and the new tagging system for the electrons and positrons from the reaction $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$, giving the opportunity to investigate $\gamma\gamma$-physics [1] at DAΦNE. A detailed description of the beam optics was necessary to track the leptons and choose where to place the taggers. The results of our simulation with the BDSIM toolkit show two different regions on both sides of IP for the new detectors: the Low Energy Tagger (LET) region, inside KLOE, where we can detect leptons with energies between 50 and 450 MeV; and the High Energy Tagger (HET) region, ~ 11 m away from IP, where we will detect the leptons having an energy greater than 420 MeV. In the LET region there is no energy-position correlation for electrons/positrons; for this reason the adopted solution for the LET is a calorimeter. The HET detector is located next to the first bending dipole acting like a spectrometer, spreading the trajectories in the longitudinal plane. In this region leptons show a clear correlation between energy and deviation from nominal orbit. Therefore a position detector was chosen.

The High Energy Tagger

The HET detector [4] will provide a measurement of the displacement of the scattered leptons with respect to the nominal orbit. Therefore this detector is inserted inside the machine lattice as close as possible to the beam orbit. The chosen access point is located after the dipole placed 11 m from the IP. The detector requirements can be summarized as: good time resolution to disentangle each bunch coming with a period of 2.715 ns; capability to acquire data at 368 MHz in order to reconstruct the event sincronously with KLOE; radiation hardness in order to be positioned at 30 mm from the beam; small size to allow the installation with the mechanical support inside the vacuum chamber. The final tagger detector consists of two rows of 15 BJ228 fast scintillators of $3 \times 5 \times 6$ mm^3 arranged as shown in Fig. 1 top. This configuration provides a spatial resolution of 5 mm corresponding to 2.5 MeV momentum resolution. The output light is collected by light guides coupled with HAMAMATSU R9880U-110 high quantum efficiency photomultiplier sensors. To minimize the interference with the DAΦNE vacuum system, the detector is installed inside a steel sleeve shaped box open to air on one side.

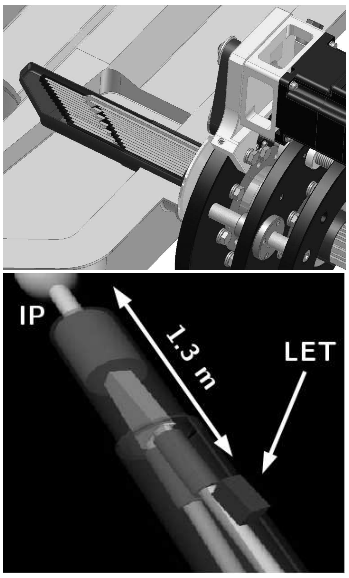

Figure 1: The HET (left) and LET (right) detectors, for the lepton tagging system.

The Low Energy Tagger

The LET detector [5] consists of a calorimeter detecting electrons and positrons with energy between 160 and 230 MeV. It is installed inside KLOE, 1.5 m away from the IP. Due to its position, radiation hard and magnetic field tolerant electronics is needed. This detector has to provide us with energy resolution better than 10%, a good time resolution to associate the detected events with the proper bunch crossing. To this purpose the LET detector is composed by 20 Lutetium Yttrium Orthosilicate (LYSO) crystal ($X_0 \sim 1$ cm) $1.5 \times 1.5 \times 13$ cm^3 each, wrapped by TYVEK and coupled to HAMAMATSU Silicon Photomultipliers with 14400 pixels and 3×3 cm^2 of active area. A preliminary study gives a resolution $\sigma_E/E = 2.4\%/\sqrt{E(\text{ GeV})} \oplus 6.5\% \oplus 5\,\text{MeV(fixed)}/E(\text{ GeV})$

STEP-1 upgrades

Major detector upgrades are foreseen for the STEP-1 planned for late 2011. All the details of the three new detectors are reported in the following.

The Inner Tracker

The Inner Tracker (IT) detector will be installed [6] between the beam pipe and the DC inner wall. It is conceived to obtain a fine vertex reconstruction in the K_S, η and η' decays and to improve the $K_S - K_L$ interference measurement. A crucial design parameter is the resolution on the reconstruction of decay points occurring within few cm from the IP. An accurate study on quantum interferometry measurement shows that an improvement on this resolution of about a factor 3 with respect to the present value ($\simeq$ 6 mm) is required [6]. The IT contribution to the overall material budget has to be taken into account in order to minimize multiple scattering contribution to the track momentum resolution and photon conversions before the DC volume. The requirements for this detector are: good space resolution $\sigma_{r\phi} \sim 200\ \mu$m and $\sigma_z \sim 500\ \mu$m; total material budget below 2% of a radiation length (X_0); rate capability 5 kHz/cm^2. The adopted solution is a Cylindrical-GEM (CGEM) detector. The IT will be composed by 4 CGEM layers with radii from 13 to 23 cm from the IP. The total active length for all layers will be 70 cm and the read-out composed of XV strips-pads with $\sim 40^\circ$ stereo angle. The radiation length in the active volume including the carbon fiber support is only 1.5% X_0. A full-scale CGEM prototype has been build and tested at CERN PS with a 10 GeV pion beam. The spatial resolution obtained from this preliminary test is $\sigma \sim 200\ \mu$m and 99.6% efficiency. In order to test the effect of the magnetic field on the readout, a 10×10 cm^2 planar GEM (PGEM) with 650 μm pitch XV strips has been realized and tested in magnetic field. The test has been performed at the H4 permanent facility, setup at CERN-SPS with a 150 GeV pion beam line, and with the GOLIATH magnet providing a field adjustable up to 1.5 T. The effect of the magnetic field is twofold: a displacement and a spread of the charge over the readout plane. In the test beam configuration the magnetic field effect was mainly present on the X-view. The displacement along the direction sensitive to the magnetic field is reported in in Fig. 2. The resolution on the x-coordinate as a function of the magnetic field ranges from 200 μm at B = 0 T up to 380 μm at B = 1.35 T.

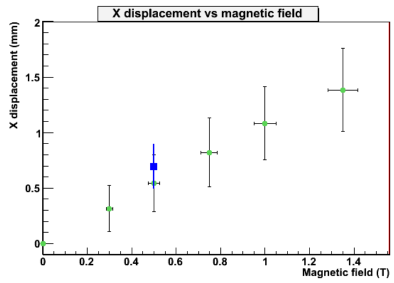

Figure 2: Displacement on x-axis as a function of the magnetic field (green points) with the result from GARFIELD simulation at $B = 0.5$ T (blue square).

The QCALT

Particles coming from a secondary vertex inside the drift chamber volume, can hit one of the quadrupoles and not be detected. In order to recover these particles two calorimeters surround the quadrupoles. An upgrade of this calorimeter (QCALT) [7] will be installed in the STEP-1 with improved performance. Its time resolution will be less than 1 ns, 10 times faster than the old calorimeter. The QCALT will increase the detection efficiency and its higher granularity will help on reducing accidental losses. The measurement of some rare decays, e.g. $K_L \to \pi^0\pi^0$ will benefit from the improved QCALT performance, rejecting the most important background sources from $K_L \to 3\pi^0$. The QCALT detector, shown in Fig. 3 top, will be composed of two tile calorimeters, a wavelength shifter and SiPM readout. It will have a dodecagonal structure 1 m long made by 5 layers of tungsten 3.5 mm thick, tiles 5 mm thick and air gap of 1 mm for a total of 4.75 cm (5.5 X_0); 20 cells/layer (100 SIPM/module) for a total of 2400 readout channels. The QCALT will be located just outside the Inner Tracker, it will have a granularity of $5 \times 5 \div 5 \times 7.7$ cm^2 per tile.

The CCALT

In order to increase the angular efficiency of the KLOE electromagnetic calorimeter, an additional small detector will be placed as shown in Fig. 3 bottom. The present EMC covers down to 21 degrees; with CCALT the coverage will go down to 8 degrees [8]. With such a detector we can for instance improve the measurement of the branching ratio of the reaction $K_S \to \gamma\gamma$ [9]: the major background for this process is the decay $K_S \to \pi^0\pi^0 \to 4\gamma$, with two photons lost in the beam pipe or lost because of some EMC inefficiency. The CCALT will be composed of 2 small barrels of 24 LYSO crystals each, with a length of 10-13 cm and transverse area from 1.5×1.5 cm^2 to 2×2 cm^2.

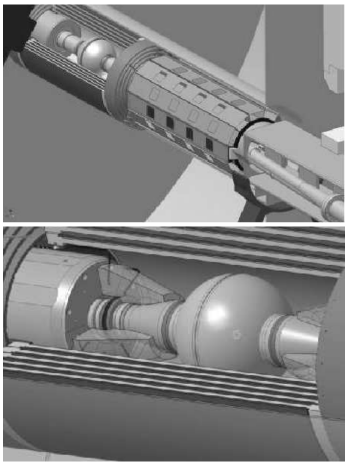

Figure 3: The QCALT calorimeter (top) and the CCALT calorimeter (bottom).

Conclusion

The new interaction region has been installed and the KLOE detector, after a successful roll-in, is now working properly. The magnetic field has been switched on and the first calibrations of DC and EMC have been done. The LET detector is installed, the HET mechanics has been installed and the detector has been constructed and is ready to be installed. DAΦNE commissioning just started.

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