The KLOE-2 experiment at DAΦNE upgraded in luminosity

Francesco Gonnella[a] on behalf of the KLOE-2 collaboration.

[a]INFN and University of Rome "Tor Vergata",
via della Ricerca Scientifica, 1 - 00133 Roma, Italy

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, while the insertion near the interaction point of an inner tracker is planned for the next year. The interaction region of DAFNE has been modified using a crabbed waist scheme. It has been successfully tested providing an improvement in luminosity of a factor 3. The KLOE-2 scientific programme [1] 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, the contribution of hadron vacuum polarization to μ anomalous moment.

1. FROM KLOE TO KLOE-2

The KLOE apparatus consists of a large volume drift chamber surrounded by an electromagnetic calorimeter and it operates in a magnetic field of 0.52 T.
It has collected 2.5 fb^{-1} of data at the $\phi(1020)$ peak plus additional 250 pb^{-1} off-peak ($\sqrt{s} = 1$ GeV) at DAΦNE, the e^+e^- collider of INFN Laboratori Nazionali di Frascati, during the years going from 2000 to 2006. The experiment achieved several precision results in many fields, such as: the kaon sector, light meson spectroscopy and measurement of the hadronic cross section below 1 GeV [2].

1.1. DAΦNE upgrade

In 2008 the DAΦNE collider has been successfully upgraded with a new interaction scheme. This new scheme consists of: large crossing angle; reduced beam size at the crossing point; sextupole pairs for crab-waist configuration.

It provides a peak luminosity of about 5×10^{32} cm^{-2} s^{-1}, a factor of 3 larger than the previous performances with the same beam currents (see Fig.1).

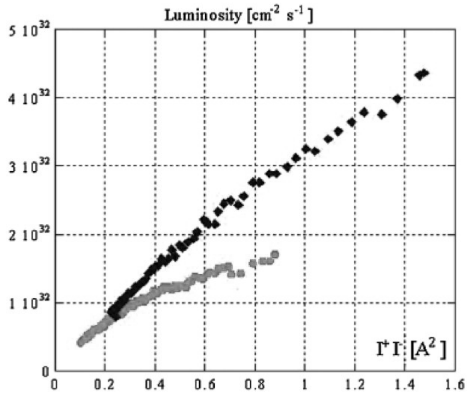

Figure 1. DAΦNE upgrade results in luminosity. Grey dots represent the old performance, black dots the performance with the crab/waist upgrade.

DAΦNE can run in a range of ±20 MeV from the ϕ peak without loss of luminosity, with the same magnetic configuration. Minor modifications, i.e., a new final particle focusing system, are needed to extend the range up to ±100 MeV while a major upgrade of the machine is required to extend it above this limit. The improved KLOE detector will be perfectly suited for taking data also at energies away from the ϕ mass. Therefore a proposal to perform the challenging and needed precision measurements of (multi)hadronic and $\gamma\gamma$ cross sections at energies up to 2.5 GeV has also been put forward.[3]

1.2. Detector improvements

Several upgrades have also been approved for the detector. In a first phase, referred to as STEP-0, two different detectors, namely Low Energy Tagger (LET) and High Energy Tagger (HET) will be installed along the beam line to detect the scattered electrons/positrons from $\gamma\gamma$ interactions. In a second phase, referred to as STEP-1, a light-material internal tracker (IT) will be installed in the region between the beam pipe and the drift chamber to improve charged vertex reconstruction and to increase the acceptance for low p_T tracks. Crystal calorimeters (CCALT) will cover the low θ region, aiming at increasing acceptance for very forward electrons/photons down to 8°. A new tile calorimeter (QCALT) will be used to instrument the DAΦNE focusing system for the detection of photons coming from K_L decays in the drift chamber.

The integrated luminosity for the two phases will be 5 fb^{-1} and 20 fb^{-1}, respectively.

2. STEP-0 UPGRADES

The STEP-0 phase will start new data taking with the old KLOE detector plus the lepton tagging system in the end of 2010.

The results of our simulations show that we need to place new detectors in two different regions on both sides of the IP: the Low Energy Tagger (LET) region where we can detect leptons with an energy between 50 and 450 MeV; and the High Energy Tagger (HET) region, where we will detect the final leptons having an energy greater than 420 MeV. We found that in the LET region, the energy of the leptons is uncorrelated to the position of the hitting point. For this reason the LET detector has to be a calorimeter. The HET detector is located just at the exit of the machine dipole, where leptons show a clear correlation between energy and deviation from nominal orbit. So in this case a position detector, measuring these deviations allows to infer the energies of the particles, is used.

2.1. The Low Energy Tagger detector

The LET detector [4] consists of a calorimeter detecting electrons and positrons within an energy range between 160 and 230 MeV. Inside the KLOE detector (1.5 m away form the IP, see Fig. 2 (right)), the environmental conditions require radiation-tolerant devices, insensitive to magnetic fields. Moreover this detector has to provide a good energy resolution in the measurement of the $\gamma\gamma$ invariant mass from the decay product, a good time resolution to associate the detected events with the proper bunch crossing, and a small size. A right choice to fulfill these requirements could be a high-Z scintillator with high light yield and fast emission. Furthermore the readout devices must be radiation hard photodetector insensitive to magnetic field. To this purpose the new Cerium doped Lutetium Yttrium Orthosilicate (LYSO) crystal scintillators were chosen, coupled to Silicon Photomultipliers (SiPM).

2.2. The High Energy Tagger detector

The HET detector [5] 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 line. The chosen access point is located after the dipole placed 11 m from the IP. The physical requirements are summarized as follows: good time resolution to disentangle each bunch coming with a period of $\sim$ 2.7 ns; capability to acquire data at a frequency of 368 MHz in order to permit event reconstruction with the KLOE apparatus; radiation hardness in order to stand 30 mm from the beam; and tiny size to allow the installation with the mechanical support inside the vacuum chamber. The tagger detector consists of a set of scintillators arranged as described in Fig. 2 (left) and is constituted of 30 small BJ228 fast scintillators $3 \times 5 \times 6$ mm^3, which provide, in this geometry, a spatial resolution of 2 mm (500 keV on momentum). 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.

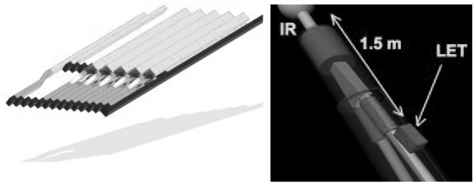

Figure 2. The HET (left) and LET (right) detectors, for the lepton tagging system.

3. STEP-1 UPGRADES

Implementation of the STEP-1 phase is planned for late 2011. Details of the planned upgrade will be discussed in the following.

3.1. The Inner Tracker detector

An Inner Tracker detector will be installed to improve vertex reconstruction [6].
It will be very useful in process involving K_S , η, η' rare decays and K_S- K_L interference measurements.
The requirements for this kind of detector are:

- Good space resolution: $\sigma_{r\phi} \sim 200\ \mu$m and $\sigma_z \sim 500\ \mu$m;
- Low material budget:¡2% X_0
- High rate capability: 5 kHz/cm^2.

In order to build the Inner Tracker we have chosen to use the GEM techonlogy.

The IT will be composed of 4 Cylindrical GEM layers (see Fig.3) with radii from 13 to 23 cm from the Interaction Point and before Drift Chamber inner wall. It will have a 700 mm long active area and will be read out with XV strips-pads (40 degrees stereo angle).

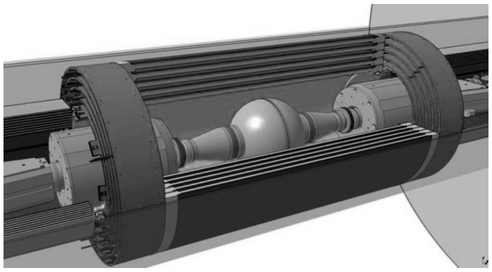

Figure 3. The Inner Tracker detector.

In order to place as few material as possible between the IP and the DC the detector will have only a 1.5% X_0 total radiation length in the active region, thanks to mechanical supports made of carbon fiber.

3.2. The QCALT calorimeter

Particles coming from secondary vertex inside the drift chamber volume, can hit one of the quadrupoles and not be detected.
For this reason we already had a calorimeter around the quadrupole in the past: the QCAL detector. The new QCALT calorimeter [7], that will be installed in the STEP-1, will provide much better performances.
The QCALT will increase the detection efficiency and the high granularity will help on reducing accidental losses. The measurement of some rare decays, e.g. $K_L \rightarrow 2\ \pi^0$ will gratly benefit from the improved QCALT performance, rejecting the most important background sources in the measurement as $K_L \rightarrow 3\ \pi^0$.

The QCALT detector, shown in Fig. 4, will be composed of two tile calorimeters, a wavelength shifter and SiPM readout. It will have a dodecagonal structure (1 m length) made by 5 layers of tungsten (3.5 mm) + tiles (5 mm) + air gap (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 (tiles). Its time resolution will be less than 1 ns, 10 times faster than the old QCAL.

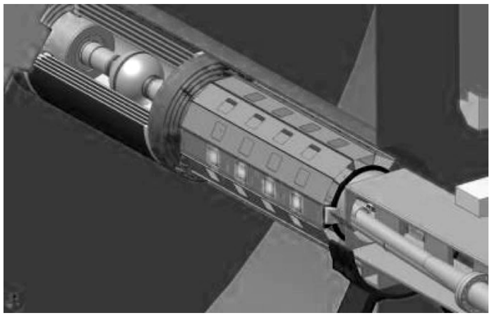

Figure 4. A scheme of the QCALT detector.

3.3. The CCALT calorimeter

In order to increase the angular efficiency of the KLOE Electromagnetic Calorimeter, an additional small detector will be placed as shown in Fig. 5. 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 improve the measurement of the branching ratio of the reaction K$_S \to \gamma\gamma$[9].

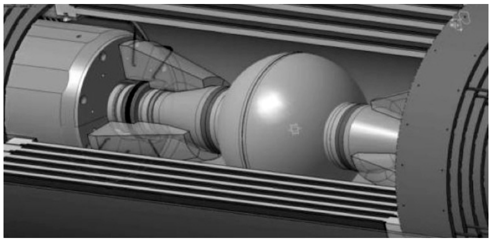

Figure 5. The CCALT calorimeter.

The major background for this process is the decay channel K$_S \to \pi^0\pi^0 \to 4\gamma$, with two photons lost in the beam pipe or due to the EMC inefficiency.

With the CCALT calorimeter we will increase the efficiency on small angle photon detection, thus improving the precision on this measurement.

The CCALT will be made of 2 small barrels of 24 LYSO crystals each, with a length of 10-13 cm and transversal area from 1.5×1.5 cm^2 to 2×2 cm^2.

4. CONCLUSIONS

The new beampipe, for the crab-waist configuration, is ready and installed. The KLOE detector, after a successful roll-in, is now up and running. The LET detector is tested and installed and the HET mechanics has been installed. The detector has been constructed and is going to be installed. DAΦNE commissioning is starting.
Work is in progress.

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