The KLOE-2 Project

Fabio Bossi
Laboratori Nazionali di Frascati of INFN,
via Enrico Fermi 40, 00044 Frascati, Italy
E-mail: fabio.bossi@lnf.infn.it

Abstract. By the end of 2009 the KLOE-2 detector is expected to start data taking at the improved DAΦNE φ-factory of the Laboratori Nazionali di Frascati of INFN. The KLOE-2 physics program is wide, spanning from studies on neutral kaon quantum interferometry, to precise tests of lepton flavour violation, to low energy QCD studies.

In this paper, the status of the project is described. Some more attention is given to the contribution of KLOE-2 to the study of discrete symmetries conservation/violation.

1. DAΦNE and KLOE: the recent past

After 8 years of increasingly successful operation, the DAΦNE e+e− collider of the INFN’s Laboratori Nazionali di Frascati (LNF) has started a new phase of life.

Between years 2000 and 2007 the machine has delivered about 4 fb−1 of data around the φ(1020) peak to three different experiments. KLOE [1], a multipurpose experiment, devoted mainly to the study of K meson decays, as well as to several hadronic physics and low energy QCD studies. FINUDA [2], devoted to hypernuclear spectroscopy. DEAR [3], for the observation and study of kaonic atoms.

In 2005, DAΦNE has reached the record peak luminosity of $1.5 \times 10^{32}$ cm$^{-2}$s$^{-1}$ (it was more than one order of magnitude lower in 2001) routinely delivering $\sim 8$ pb$^{-1}$ per day to the experiments. Thanks to this performance, KLOE has collected 2.5 fb$^{-1}$ in its five years of data taking. It should be reminded that previous experiments at the same energy have collected statistics of a few dozens pb$^{-1}$: this well quantifies the success of the enterprise.

KLOE is a typical modern e+e− detector: its main components are a large cylindrical drift chamber, $\sim 3.5$ m long and 2 m radius, surrounded by a lead-scintillating fibers electromagnetic calorimeter. A superconducting solenoid provides a magnetic field of 0.52 T.

Among the many physics results published by the Collaboration so far, i would like to mention:

- The precise determination of the CKM element $V_{us}$, obtained using the measurements of several independent neutral and charged $K$ meson parameters [4]. Thanks to this determination, the unitarity of the first row of the CKM matrix has been tested with a precision of 0.6 per mil.

- The precise measurement of the hadronic cross section below 1 GeV, a key ingredient for the theoretical evaluation of the muon $g - 2$ [5, 6]. This is particularly relevant, since this determination might point to a $\sim 3$ sigma discrepancy between theory and experiment, and a possible hint for new physics.
Precise tests of CPT symmetry conservation in the neutral kaon system, using different techniques [7, 8].

In June 2006, after a three-months off-peak run, the detector was rolled out and parked in the nearby assembly hall, waiting for a possible future use.

2. The DAΦNE upgrade

Already in year 2003, a lively debate has started in the laboratory about the future of DAΦNE and of LNF in general. It became immediately clear that very ambitious projects for an increase of the DAΦNE luminosity by a factor \( \sim 100 \) required the construction of a totally new accelerator. In 2006, P. Raimondi and collaborators have proposed the implementation of a new interaction scheme in DAΦNE, resulting in an increase in luminosity by a factor between 3 and 10, at the price of minimal changes in the hardware setup [9]. The idea, that combines the use of a larger crossing angle with a proper rotation of the optical functions of the beams at the interaction point ("crabbed waist" scheme), is particularly attractive, since it can be applied also to other projects for future super-luminous flavor factories.

It was therefore decided to test the scheme during the run of SIDDHARTA [10], the latest-born among the DAΦNE experiments, which has started data taking at the beginning of 2008. After a period of machine tuning, the most recent results are striking. Peak luminosities up to \( 4 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \) have been repeatedly obtained, with colliding currents comparable or slightly lower than those used for the previous DAΦNE records. A maximum daily integrated luminosity of 12.5 \( \text{pb}^{-1} \) was also achieved. There are also solid hints that these records can be beaten. On a two-hour basis, a hourly integrated luminosity of 0.7 \( \text{pb}^{-1} \) has been obtained, which points to a possible luminosity per day of 17 \( \text{pb}^{-1} \); noticeably enough, this last achievement has been obtained with a relatively moderate injection frequency, required by SIDDHARTA for the proper operation of the detector (KLOE, in fact, can operate in an almost continuous injection regime).

Taking all the previous considerations into account, it is fair to say that LNF has now a machine capable of delivering \( \sim 4 \text{ fb}^{-1} \) in one year (i.e. what it has delivered in its entire lifetime so far), with still some margin of improvement.

3. The KLOE-2 Project

A proposal for the continuation of the KLOE experiment on the upgraded machine, and with an upgraded detector has been put forward since 2006 [11]: this is the KLOE-2 project.

A high statistics data sample will allow KLOE-2 to reach significant sensitivities in the studies of the entangled system of the neutral kaons, in the experimental test of lepton universality and in the measurement of several rare \( K_S, \eta \) and \( \eta' \) decays. On the other hand, many of the above mentioned studies can benefit of a few well defined detector’s upgrades, i.e. the insertion of new subdetectors, both tracking devices and calorimeters, in the very core of the apparatus, close to the interaction region. More specifically, KLOE-2 plans to install a very light tracker (a cylindrical GEM detector) in the space between the DC and the spherical beam pipe, which is presently empty. This is a novel technique, which is being developed mainly at LNF. Crystal calorimeters, in front the low-\( \beta \) quadrupoles, will increase acceptance for very low-\( \theta \) photons, a key issue for some rare decay studies. KLOE-2 wants also to extend its field of interest to the study of \( \gamma\gamma \) reactions, by inserting dedicated detectors to tag the scattered electron and positron, typical of these events.

Most of this new hardware requires time to be designed, prototyped and tested before insertion. Therefore a two-step roll-in strategy has been proposed. First, the detector will be reinstalled as it is, with the minimal modifications required for a safe and efficient run (step 0). A first period of data taking in these conditions, will allow the Collaboration to study the detector’s response to the new machine conditions, and to integrate enough statistics to
Figure 1. Precision reachable by KLOE-2 in the measurement of the CPT violating parameters $\alpha\beta$ and $\gamma$ of the model of reference [12], as a function of the integrated luminosity and for the two cases with (black circles) and without (open circles) internal tracker.

improve on some specific physics channels. In the second phase, step 1, the most demanding upgrades will be installed, with the goal of running for a few years to exploit the full potentials of the project.

4. Discrete symmetries studies with KLOE-2
As stated before, the KLOE-2 program covers a wide variety of physics topics. Since the present Conference is devoted to the study of discrete symmetries, I will concentrate in this section to the contributions that KLOE-2 can give in this field.

A $\phi$-factory is a unique place to investigate the evolution of the entangled system of neutral kaons, which is sensitive to decoherence phenomena possibly induced by CPT violation. For a complete review of these very fundamental studies I refer the reader to Antonio Di Domenico’s contribution to this Conference. Here, I would like just to stress the extraordinary potential of KLOE-2 in this field, which can largely improve with respect to KLOE, both due to the increased statistics and to the improved detector. Figure 4 shows the reachable precision in the measurement of the CPT violating parameters $\alpha\beta$ and $\gamma$ of the model of reference [12], as a function of the integrated luminosity and for the two cases with and without internal tracker. The possible improvement with respect to the present situation (dominated by CPLEAR measurements) is striking.

CPT symmetry can also be tested using neutral kaons semileptonic decays. Actually, the charge asymmetries of the short and long lived $K^0$ mesons for these reactions must be equal.
under CPT conservation. The $K_L$ asymmetry is known today with a precision of order $10^{-5}$ [13], while the $K_S$ one, measured by KLOE using $\sim 400 \text{ pb}^{-1}$ of data, is known at the per cent level [14]. KLOE-2 aims at reaching a $10^{-3}$ precision.

$K_S$ decays into three neutral pions are purely CP violating. Unfortunately, the branching ratio for this decay is expected to be $\sim 10^{-9}$. KLOE has set the best limit to date on this branching ratio: $1.2 \times 10^{-7}$ at 90% C.L [15]. KLOE-2 can improve a lot on that, and might hope to observe the signal for the first time. Improvements can arrive not only on the statistics side; in fact, usage of the forward calorimeters can improve the rejection of the $K_S \rightarrow 2\pi^0$ events, the most relevant systematical limitation for the measurement.

Unconventional forms of CP violation can also be tested using $\eta$ meson decays to $\pi^+\pi^-e^+e^-$. Actually, thanks to the $\phi$ radiative decay to $\eta\gamma$, DAΦNE can also be considered a clean source of well tagged $\eta$ mesons. About $10^9 \eta$'s will be collected by KLOE-2 in a few years of data taking. With this sample an asymmetry as small as $10^{-3}$ can be measured.

KLOE has already put limits on the rates of $\eta \rightarrow \pi^+\pi^-$ [16] and $\eta \rightarrow e^+e^-$ [17] decays, two processes which are forbidden by invariance under P and C transformations. Using the full KLOE-2 statistics one can improve the above results by about two orders of magnitude; these will be the most precise test ever done of P and C conservation in strong and electromagnetic interactions.

5. Conclusions

The recent success of DAΦNE has put the KLOE-2 project on the launching pad. The two-steps data taking campaign will start by the end of 2009 and last for at least other three-four years.

Several relevant physics issues will be addressed by the experiment, many of which directly connected to discrete symmetries conservation. We are therefore very confident that we can report the first results of KLOE-2 at the next edition of this Conference.

References

[1] Bossi F. et al. 2008 Riv. Nuovo Cimento 31 10 1
[2] Agnello M. et al. 2007 Nucl. Inst. Meth. A 573 205
[3] Ishiwatari T. et al. 2004 Phys. Lett B 593 48
[4] Ambrosino F. et al. 2008 J. High Energy Phys. JHEP04(2008)059
[5] Aloisio A. et al. 2005 Phys. Lett B 606 12
[6] Ambrosino F. et al. 2009 Phys. Lett B 670 285
[7] Ambrosino F. et al. 2006 Phys. Lett B 642 315
[8] Ambrosino F. et al. 2006 J. High Energy Phys. JHEP12(2006)011
[9] Alesini D. et al. 2006 LNF-06/33 (IR) 1
[10] Curceanu-Petrascu C. et al. 2007 Eur. Phys. J. A 31 537
[11] Beck R. et al. 2006 http://www.lnf.infn.it/hfadmin/direzione/KLOE2-LoI.pdf
[12] Ellis J. et al. 1984 Nucl. Phys. B 241 381
[13] Amsler C. et al. (2008) Phys. Lett. B 667 1
[14] Ambrosino F. et al. 2006 Phys. Lett B 636 173
[15] Ambrosino F. et al. 2005 Phys. Lett B 619 61
[16] Ambrosino F. et al. 2005 Phys. Lett B 606 276
[17] Aloisio A. et al. 2004 Phys. Lett B 591 41