The Frascati $e^+e^-$ collider, DAΦNE, operates at a center of mass energy around the mass of the $\phi$-meson ($\sqrt{s} \sim 1020$ MeV) since 1999. The KLOE experiment, designed to measure CP and CPT violation parameters in the $K_sK_L$ system, runs in one of the two DAΦNE interaction regions and has collected so far $\sim 500$ pb$^{-1}$. After a brief description of the accelerator complex and the detector, we present the physics measurements obtained using the year 2000 data sample ($\sim 17$ pb$^{-1}$). These first measurements are statistically limited and are therefore focussed on $\phi$ radiative decays and $K_S$ physics. We also highlight the measurements in progress on the entire data sample.
1 The Frascati $\phi$–factory complex

$\text{DA}\Phi\text{NE}^1$ is an $e^+e^-$ collider operating at a center of mass energy of $\sim 1020$ MeV, the mass of the $\phi$-meson. At the design peak luminosity of $5 \times 10^{32}$ cm$^{-2}$s$^{-1}$, the machine will produce $\sim 1.5$ kHz of $\phi$'s. The accelerator complex consists of an injection system and a collider, composed by two main rings, in which electron and positron beams circulate separately. Two interaction regions (IR) house the experiments: KLOE$^2$ on one side, DEAR (FINUDA)$^3,4$ on the opposite one. The main physics interest, motivating the construction of such a complex, is the measurement of the CP-violation parameter $\varepsilon'/\varepsilon$ using the KLOE detector. The two other experiments are designed to operate sequentially to perform high-precision measurements in nuclear and atomic physics.

The injection system is based on a 60 m long Linac, which can accelerate electrons (positrons) up to energy of 800 (550) MeV. An intermediate 33 m long accumulator ring is used to damp the transverse and longitudinal emittances of the Linac beam, thus relaxing the injection requirements in the collider. The strategy used to achieve a high luminosity consists in accumulating high-current electron and positron beams (5 A at maximum) of 120 bunches each. Two rings are needed in order to minimize perturbations due to beam-beam electromagnetic interactions. The beams intersect at the two IR’s with a horizontal crossing angle of $\sim 25$ mrad. The $\phi$’s produced at resonance energy have small momentum ($P_{\phi} \sim 13$ MeV/c) in the laboratory frame.

At present, $\text{DA}\Phi\text{NE}$’s peak luminosity is $7.8 \times 10^{31}$ cm$^{-2}$s$^{-1}$, still a factor 7 smaller than the design value. This is obtained with $\sim 800$ mA circulating beam currents. The luminosity delivered to KLOE is on average 2.5 pb$^{-1}$ per day (4 pb$^{-1}$ at maximum). This is achieved since KLOE is able to operate in the "top-up" injection mode, i.e. injecting electrons and positrons with colliding beams every fifteen minutes. This mode of operation is well suited for $\text{DA}\Phi\text{NE}$, because of its short beam lifetimes, which are reflected in a steep drop-off of the luminosity with time.

KLOE had three different data-taking periods: the first was in 1999, mostly spent in machine and detector commissioning. In year 2000 the machine delivered to KLOE a total of 23 pb$^{-1}$, which yielded the first relevant physics results. In year 2001 a total integrated luminosity of 180 pb$^{-1}$ has been collected. In year 2002 data taking has resumed in May, with slightly higher luminosity, but with much improved machine background conditions, which is another key issue for many physics measurements. The 2002 run ended in September, adding another 300 pb$^{-1}$ on tape.
<table>
<thead>
<tr>
<th>$\phi$ decay channel</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+K^-$</td>
<td>0.492 ± 0.007</td>
</tr>
<tr>
<td>$K_SK_L$</td>
<td>0.337 ± 0.006</td>
</tr>
<tr>
<td>$\pi^+\pi^0\pi^0 + \rho\pi$</td>
<td>0.155 ± 0.006</td>
</tr>
<tr>
<td>$\eta\gamma$</td>
<td>0.0013 ± 0.0003</td>
</tr>
</tbody>
</table>

Table 1. Main decay channels of the $\phi$ meson and their branching ratio (BR).\(^5\)

2 The KLOE experiment

The main decay channels of the $\phi$ meson are listed in Tab. 1. The accelerator complex DAΦNE is therefore not only a factory of $K_SK_L$ but also a factory of $K^+K^-$, $\rho$ and $\eta$ mesons. In the case of the kaons, pure\(^*\) monochromatic, low momentum $K\bar{K}$ beams ($P_K \sim 110, 126$ MeV for the neutral and charged pairs respectively) are produced. This provides an efficient tagging in both cases. The low speed of the kaons is also a strong motivation for relying on time of flight in many steps of the event reconstruction.

2.1 The physics program

The KLOE scientific program\(^2\) is focussed on the study of CP and CPT symmetries with neutral kaons. The design of the experiment was driven by the measurement of the direct CP violation via the, by now classical, “double ratio method”:

$$R_d = \left| \frac{\eta_\pm}{\eta_0} \right|^2 = \frac{N(K_L \to \pi^+\pi^-)}{N(K_S \to \pi^+\pi^-)} \times \frac{N(K_S \to \pi^0\pi^0)}{N(K_L \to \pi^0\pi^0)} = 1 + 6 \Re(\epsilon'/\epsilon).$$ \(^{(1)}\)

Although the fix target experiments (NA48, KTeV) have already proved the existence of direct CP violation in the kaon system by establishing that $\Re(\epsilon'/\epsilon)$ is consistently different from zero,\(^\dagger\) a new measurement from KLOE could allow us to reach a similar sensitivity with a completely different systematics. But, to reach an accuracy of the order of $10^{-4}$, an integrated luminosity in the range of several fb\(^{-1}\)'s is needed. However, if and when this statistics will be collected, since the $K\bar{K}$ pairs are produced in a pure quantum state ($J^{PC} = 1^{-+}$, the same of the $\phi$ meson) other interesting CP, CPT parameters become

\(^4\)In the case of the neutral kaons, from unitarity and from $\sigma(\gamma\gamma \to K^0\bar{K}^0, J^{PC} = 0^+)$, the ratio of the processes $(e^+e^- \to K_SK_S + K_LK_L)/(e^+e^- \to K_SK_L)$ is few $\times 10^{-10}$.

\(^\dagger\)The most recent measurements report: $(20.7 \pm 2.8) \times 10^{-4}$ (KTeV), $(14.7 \pm 2.2) \times 10^{-4}$ (NA48), $(16.7 \pm 2.3) \times 10^{-4}$ (world average).
accessible to KLOE by looking at the quantum-mechanical interference patterns in the time evolution of the $K_S K_L$ system.\(^6\)

At present, although the CP, CPT measurements are out of reach, many other physics topics can be studied with the collected statistics. Analyses on the year 2000 data set have produced new results on the $\phi$ radiative decays into scalar ($f_0$, $a_0$) and pseudoscalar ($\eta$, $\eta'$) mesons, on the $K_S$ semileptonic decay, and on the ratio of $K_S$ decays into charged and neutral pion pairs. Using the whole data set (500 pb\(^{-1}\)), the goal is to improve the accuracy on the Cabibbo angle ($V_{us}$) through precise measurements (0.2\%) of both $K_L$ and charged kaon semileptonic decays; a better than 1\% measurement of the $e^+ e^-$ hadronic cross section below 1 GeV, and several measurements of rare $K_S$ and $K_L$ decays.

### 2.2 The detector

At DAΦNE’s energies the $K_S$ ($K_L$) have a mean decay path of 0.6 (340) cm respectively, thus driving the experiment’s dimension. Indeed, the KLOE detector\(^7\) has been designed to maximize the number of reconstructed $K_L$ decays. It consists of a large tracking chamber, a hermetic electromagnetic calorimeter and a superconducting magnet providing a solenoidal field of $\sim 0.52$ T. The beam pipe in the interaction region is spherical in shape, 10 cm in radius in order to contain all $K_S$ decays, and is made of an Aluminum-Beryllium alloy.

The large, 2 m radius and 3.7 m long, tracking volume is instrumented with a drift chamber\(^8\) operating with a low-$Z$, 90\%He-10\%iC\(_4\)H\(_{10}\) gas mixture, enclosed by Carbon-fiber/Epoxy walls. The light $A$, $Z$ materials have been chosen to optimize the chamber resolution, and to reduce both the photon conversions ($0.01 X_0$) and $K_L \to K_S$ regeneration. The 58 concentric layers of wires (52140 wires, 12582 readout channels) are strung in an all-stereo geometry. The momentum resolution is $\sigma(p_\perp)/p_\perp \simeq 0.4\%$, from a single measurement of spatial resolution of $\sigma_{r\phi} \sim 150 \ \mu$m ($\sigma_z \sim 2$ mm).

The electromagnetic calorimeter\(^9\) is a sampling calorimeter made of lead and scintillating fiber layers, 15 $X_0$ thick. The solid angle coverage (98\%) is ensured by barrel modules surrounding the drift chamber and by modules of two endcaps, which are bent outwards to eliminate dead zones in the overlap region between barrel and endcap. The calorimeter modules are read out at the two ends by a total of 4880 photomultipliers. The calorimeter has been designed to measure time and energy for photons of energy as low as 20 MeV, with resolutions of $54 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 50 \text{ ps}$ in time and $5.7\% / \sqrt{E(\text{GeV})}$.
### Table 2. Radiative decays of the $\phi$ meson.

<table>
<thead>
<tr>
<th>Radiative decay</th>
<th>BR (PDG)</th>
<th>decay type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta \gamma$</td>
<td>$(1.30 \pm 0.03) \times 10^{-2}$</td>
<td>$\phi \rightarrow P(0-+)\gamma$</td>
</tr>
<tr>
<td>$\pi^0 \gamma$</td>
<td>$(1.24 \pm 0.10) \times 10^{-3}$</td>
<td>$\phi \rightarrow P(0-+)\gamma$</td>
</tr>
<tr>
<td>$\eta' \gamma$</td>
<td>$(6.7 \pm 1.5) \times 10^{-5}$</td>
<td>$\phi \rightarrow P(0-+)\gamma$</td>
</tr>
<tr>
<td>$f_0 \gamma$</td>
<td>$(3.3^{+0.8}_{-0.5}) \times 10^{-4}$</td>
<td>$\phi \rightarrow S(0++)\gamma$</td>
</tr>
<tr>
<td>$a_0 \gamma$</td>
<td>$(8.8 \pm 1.7) \times 10^{-5}$</td>
<td>$\phi \rightarrow S(0++)\gamma$</td>
</tr>
</tbody>
</table>

in energy.

### 3 KLOE first physics results

As already explained, the KLOE physics program is really a function of the integrated luminosity. In year 2002, we have published few papers on radiative decays and $K_S$ physics that are summarized in the following paragraphs.

#### 3.1 Results on $\phi$ radiative decays

The radiative decays of the $\phi$ meson offer a probe to study the nature of light scalar and pseudoscalar mesons. These processes are summarized in Tab. 2. The first papers focused the search on radiative decays with BR of $\sim 10^{-4}$.

#### 3.1.1 The pseudoscalar sector

In the pseudoscalar sector, the magnitude of the $\phi \rightarrow \eta' \gamma$ decay is sensitive to the $s\bar{s}$ and gluonium content of the $\eta'$ which is not fully excluded from the existing measurements. A high precision measurement of the branching ratio BR($\phi \rightarrow \eta' \gamma$) is relevant for clarifying this point. According to the quark model (assuming no gluonic content for $\eta'$) the $\pi^0$, $\eta$, and $\eta'$ mesons are described, in the quark-flavour basis, as follows:

$$|\pi^0\rangle = \sqrt{\frac{1}{2}} (|u\bar{u}\rangle + |d\bar{d}\rangle)$$  \hspace{1cm} (2)

$$|\eta\rangle = \cos(\alpha_p)/\sqrt{2}(|u\bar{u}\rangle + |d\bar{d}\rangle) + \sin(\alpha_p)|s\bar{s}\rangle$$  \hspace{1cm} (3)

$$|\eta'\rangle = -\sin(\alpha_p)/\sqrt{2}(|u\bar{u}\rangle + |d\bar{d}\rangle) + \cos(\alpha_p)|s\bar{s}\rangle$$  \hspace{1cm} (4)
where $\alpha_p$ represents the pseudoscalar mixing angle in the flavour basis. From the above equations, and assuming the $\phi$ meson to be $s\Xi$, the ratio of the BR’s for the processes $\phi \rightarrow \eta'\gamma$ (PSa) and $\phi \rightarrow \eta\gamma$ (PSb) is related to $\alpha_p$. A complete derivation of this ratio can be found in Ref. 15 and is parametrized as:

$$R_{\phi\eta\eta'} = \frac{\text{BR}(\text{PSa})}{\text{BR}(\text{PSb})} = \cotg(\alpha_p)^2 \left| \frac{K(\eta')}{K(\eta)} \right|^3 F(\alpha_p, \alpha_v)$$

(6)

where $K$’s are the radiative photon momenta in the $\phi$ center of mass and $F$ is a slowly varying function which takes into account also the correct quark structure of the $\phi$ meson.

The events PSa, PSb are selected using the decay chains:

- $\phi \rightarrow \eta'\gamma$ with $\eta' \rightarrow \eta \pi^+\pi^-$ and $\eta \rightarrow \gamma\gamma$;
- $\phi \rightarrow \eta\gamma$ with $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\pi^0 \rightarrow \gamma\gamma$;

The same final state $\pi^+\pi^-\gamma\gamma\gamma$ is searched for both reactions, thus allowing the can-
cellation of many systematic effects in the measurement of $R_{\phi \to \eta' \eta}$. A good separation between the $\eta' \gamma$ and the dominant $\eta \gamma$ events ($S/B \sim 1/100$) is achieved by exploiting the fact that the radiative photon has much more energy for the latter events ($\sim 360$ MeV vs $\sim 60$ MeV). Another source of background originates from other $\phi$ decays such as $\phi \to \pi^+ \pi^- \pi^0$ and $\phi \to K_S K_L$. After a preliminary event selection, requiring a two track vertex close to the IR and three neutral EMC clusters on time, a kinematic fit to the event is performed applying momentum conservation at the IR. This allows us to greatly improve the mass determination by adjusting the photon energies. A total efficiency of 22.8%, 36.4% is found for the PSa, PSb decays after applying also a loose $\chi^2$ cut and a topological cut between the energies ($E_1, E_2$) of the two most energetic photons. In Fig. 1 the scatter plot of $E_1, E_2$ is shown. The two ellipses around 360 MeV are due to the radiative photon of the $\eta \gamma$ events, while the signal for $\eta'$ is concentrated in the central ellipse. Selecting the events in this region, and reconstructing the invariant mass of the $\pi \pi \gamma \gamma$ system, a clear peak at the $\eta'$ mass value emerges over a low and flat background (see Fig. 2). The number of signal events is $124 \pm 12_{\text{stat}} \pm 5_{\text{syst}}$. The ratio of branching ratio is then obtained by normalizing to the $\eta \gamma$ observed events and by taking into account secondary BR’s$^{16}$ and detection efficiencies:$^{12}$

$$\frac{\text{BR}(\phi \to \eta' \gamma)}{\text{BR}(\phi \to \eta \gamma)} = (4.70 \pm 0.47_{\text{stat}} \pm 0.31_{\text{syst}}) \times 10^{-3}.$$

The corresponding value for the pseudoscalar mixing angle is $\alpha_P = (41.8^{+1.9}_{-1.6})^\circ$. Making use of the $\phi \to \eta \gamma$ branching ratio$^{16}$ we obtain:

$$\text{BR}(\phi \to \eta' \gamma) = (6.10 \pm 0.61_{\text{stat}} \pm 0.43_{\text{syst}}) \times 10^{-5},$$

which is the most precise determination to date. This result limits the gluonium content in the $\eta'$ state to be less than 15%.

### 3.1.2 The scalar sector

Although the existence of the scalar mesons $f_0(980)$ and $a_0(980)$ is well established, their physical nature is still unclear. Both mesons have a small width and small $\gamma \gamma$ couplings, compared to ordinary mesons of the same mass, while showing a large $K \bar{K}$ coupling. The main hypotheses are that these states are $q\bar{q}q\bar{q}$, $K \bar{K}$ molecules.$^{17,18}$ The radiative decays $\phi \to a_0 \gamma$, $\phi \to f_0 \gamma$ offer a new method to test the nature of these mesons$^{19}$ since the various models can be disentangled by precise measurements of the branching ratios and of the scalar meson mass spectra.
Fig. 2. $\phi \rightarrow \eta'\gamma$ decay: distribution of the $M_{\pi\eta\gamma}$ invariant mass, after removal of the $\eta\gamma$ identified events; the estimated residual background is also shown.

The different isospin values between these two scalars translate in different accessible final states: the $f_0$ ($I=0$) mainly decays into $\pi\pi$ while the $a_0$ ($I=1$) decays into $\eta\pi$. We have searched for the following decay chains: $f_0 \rightarrow \pi^0\pi^0$ (Sa) and $a_0 \rightarrow \eta\pi^0$ (Sb) with $\eta \rightarrow \gamma\gamma$, both yielding a five photon final state. In the case of $a_0$, another secondary decay $\eta \rightarrow \pi^+\pi^-\pi^0$ (Sc) has also been exploited, giving a final topology with two tracks and five photons. After a preliminary selection of 5 prompt photons (5 prompt photons and 2 tracks from the IR) a set of kinematic fits is performed to improve the energy resolution.

In Fig. 3 we show the quality of the data for the search (Sa) by reporting the $\chi^2$ of the kinematic fit, the reconstructed $\eta^0$ mass and various angular distributions. Black points are data while the solid curve is the MC expectation for signal+background, the background is represented by the shaded area. The total efficiency is around 41% and is almost constant as a function of the $\pi^0\pi^0$ invariant mass $M_{\eta^0\pi^0}$. Also the two other decays
Fig. 3. Data-MC comparison for $\phi \rightarrow \pi^0\pi^0\gamma$ events after preliminary selection: (a) $\chi^2/ndf$; (b) difference between reconstructed and expected $M_{\pi^0}$ value; (c),(d) angular distributions with all cuts applied. $\cos \theta$ is the polar angle of the radiative photon, $\cos \psi$ is the angle between the radiative photon and a $\pi^0$ in the $\pi^0\pi^0$ rest-frame.

show a good data-MC comparison. The decay Sb still suffers of a 30% background contamination while Sc, although statistically limited, is practically background free. This is also the first observation of such a decay.

In the 16 pb$^{-1}$ of the 2000 data sample, we count $2438 \pm 61$, $607\pm36$, $197\pm15$ signal events for the channel Sa, Sb, Sc respectively. These first studies already contain much larger statistics than the previous VEPP-2M experiments. The $M_{\pi^0\pi^0}$ (Fig. 4) and $M_{\eta\pi^0}$ (Fig. 5) spectra are then reconstructed for the selected events. The observed distributions are used to evaluate the branching ratios, after having normalized the events to the $\phi$ production cross section, as measured in the $\phi \rightarrow \eta\gamma$ ($\eta \rightarrow \gamma\gamma$) three photon
where the $\eta$ decay BR’s in the $\eta\pi^0\gamma$ final states have been scaled according to Ref. 16. The above values include possible contributions from the resonant decay $\phi \rightarrow \rho\pi^0$, followed by $\rho \rightarrow \pi^0\gamma$ or $\rho \rightarrow \eta\gamma$. In order to extract the $f_0$ and $a_0$ parameters from the mass spectra, a fit has been performed on the $M_{\pi^0\pi^0}$ and $M_{\eta\pi^0}$ distributions respectively. The model spectrum is taken as the sum of $f_0\gamma$ ($a_0\gamma$), $\rho\pi$ and interference terms. For the scalar meson contribution the formulation of Ref. 19 is used, which is based on $\phi$ coupling to a charged kaon loop. The vector meson term is taken from VMD calculations. At the end, the contribution from the $\rho\pi$ final state turns out to be negligible in both cases;
Fig. 5. $\phi \rightarrow \eta\pi^0\gamma$: $M_{\eta\pi}$ invariant mass distributions for two different samples on data after resolution and efficiency unfolding: five photons sample (open circles), and five photons and two tracks sample (black circles). The results of the fit are superimposed as a solid line. Dashed curves are the contributions of the single terms.

Moreover, a good fit to the $M_{\pi^0\pi^0}$ spectrum can only be obtained including, together with the $f_0$, a contribution from another light scalar meson ($\sigma$) and a strong negative interference term between the two. Branching ratios are finally obtained for the $f_0$ final state:

$$\text{BR}(\phi \rightarrow f_0\gamma, f_0 \rightarrow \pi^0\pi^0) = (14.9 \pm 0.7) \times 10^{-5},$$

and for the $a_0$ final state:

$$\text{BR}(\phi \rightarrow a_0\gamma, a_0 \rightarrow \eta\pi^0) = (7.4 \pm 0.7) \times 10^{-5}.$$

KLOE results on the scalar mesons, based on the 2000 data sample, are compatible with the four quarks model in the case of the $f_0$, but do not agree with the same model in the case of $a_0$ decay.
Fig. 6. Distribution of $\beta$ in the $\phi$ center of mass system, $\beta^*$, for $K_L$ interacting in the calorimeter with $K_S \rightarrow \pi^0\pi^0$ and $K_S \rightarrow \pi^+\pi^-$ selections. In the insertion, the same distributions are shown after correcting for the wrong bunch assignement.

### 3.2 $K_S$ physics results

As already stated in the introduction, neutral kaons at a $\phi$–factory are produced in a coherent $J^{PC} = 1^{--}$ quantum state, which is a superposition of $K_S K_L$ states with opposite momenta:

$$|i\rangle = 1/\sqrt{2}( |K_S, \vec{P}\rangle |K_L, -\vec{P}\rangle + |K_L, \vec{P}\rangle |K_S, -\vec{P}\rangle)$$

(10)

This allows the tagging of pure and almost monochromatic kaon beams: the detection of a $K_L$ ($K_S$) tags the presence of a $K_S$ ($K_L$) in the opposite hemisphere of the apparatus. In particular, a very robust and almost unbiased $K_S$ tag is provided by the interactions of $K_L$ in the calorimeter: in about 30% of the cases the $K_L$ does not decay in the detector, reaches the calorimeter barrel and interacts therein. A time-of-flight measurement then allows a clean selection of these interactions since $\beta_{KL} \sim 0.218$ (see Fig. 6). Results from the 2000 data set come from $5.4 \times 10^6$ tagged $K_S$. 

---

**Note:** The content includes a figure that is not described in the text. It appears to be a distribution of $\beta$ in the center of mass system, but without additional context or specifications, it is challenging to provide a precise description. The equation provided is an example of a wavefunction for a superposition state, which is relevant in the context of neutral kaon physics at $\phi$–factories.
3.2.1 The ratio $BR(K_S \to \pi^+\pi^- (\gamma))/BR(K_S \to \pi^0\pi^0)$

The first topic addressed is the measurement of the ratio:

$$R_\pi = \frac{BR(K_S \to \pi^+\pi^- (\gamma))}{BR(K_S \to \pi^0\pi^0)}$$

which is a step towards the determination of $\Re(\epsilon'/\epsilon)$ with the double ratio method. Although the double ratio is known with a precision of 0.1% the single ratios are known only with a precision of $\sim 2\%$. Our goal is to measure each single ratio with a precision of 0.1%. The precise measurement of the single ratio for the $K_S$, is also relevant for the extraction of the isospin $I = 0$, $I = 2$ amplitudes and phases for the $K \to 2\pi$
<table>
<thead>
<tr>
<th>Source of systematics</th>
<th>Relative Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event count</td>
<td>0.14</td>
</tr>
<tr>
<td>Tracking</td>
<td>0.26</td>
</tr>
<tr>
<td>Cluster counting</td>
<td>0.20</td>
</tr>
<tr>
<td>Triggering</td>
<td>0.10</td>
</tr>
<tr>
<td>Ratio of tag efficiencies</td>
<td>0.55</td>
</tr>
<tr>
<td>Cosmic-ray veto</td>
<td>0.21</td>
</tr>
<tr>
<td>Total error</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 3. Contributions to the fractional error on $R_{\pi}$.

process. In our measurement of $R_{\pi}$, effort was spent to correctly take into account the soft radiation emitted in $\pi^+\pi^-\gamma$ decay.

From the sample of tagged $K_S$ decays the ratio of $\pi^+\pi^- (\gamma)$ and $\pi^0\pi^0$ branching ratios is extracted by selecting two categories of events: 2 tracks from the IP for $\pi^+\pi^-$ decay mode, and at least three prompt photons for the $\pi^0\pi^0$. The quality of the data is shown for both samples in Figs. 7a,b. While the selection efficiency has been evaluated from the Monte Carlo simulation, all other efficiencies, such as the track reconstruction efficiency and the photon detection efficiency have been evaluated from data.

Moreover, special effort has been devoted in the assessment of the $\pi^+\pi^- (\gamma)$ selection efficiency as a function of the center of mass photon energy $E_\gamma^*$, from zero to the maximum allowed energy of $\sim 170$ MeV. In order to perform a fully inclusive measurement, the selection efficiency has been evaluated from Monte Carlo and folded into the theoretical $E_\gamma^*$ spectrum. The corrected ratio is then:

$$\frac{\text{BR}(K_S \rightarrow \pi^+\pi^- (\gamma))}{\text{BR}(K_S \rightarrow \pi^0\pi^0)} = 2.236 \pm 0.003_{\text{stat}} \pm 0.015_{\text{syst}}.$$

The contribution of the systematics errors are listed in Tab. 3. Our result is slightly higher than the current world average value ($R_{\pi} = 2.197 \pm 0.026$) although this can be expected, since our measurement includes the entire radiative spectrum.

### 3.2.2 Semileptonic $K_S$ decay

The second result is the measurement of $\text{BR}(K_S \rightarrow \pi^\pm e^\mp \bar{\nu}(\nu))$ with 5% accuracy, based on the largest sample collected so far. The amplitudes of the $K^0 \bar{K}^0$ to undergo a semileptonic decay with a determined lepton charge ($l^\pm$) are described by the following
equations depending upon if the $\Delta S = \Delta Q$ rule is satisfied or violated:

\begin{align*}
A(K^0 \to l^+) &= a + b & A(K^0 \to l^-) &= a^* - b^* & (\Delta S = +\Delta Q) \\
A(K^0 \to l^-) &= c + d & A(K^0 \to l^+) &= c^* - d^* & (\Delta S = -\Delta Q)
\end{align*}

(12)

(13)

where $a, c$ ($b, d$) are complex amplitudes CPT conserving (violating). Assuming CPT conservation, the ratio of the decay rates of the $K_S$ and $K_L$ integrated over the final lepton charge results to:

\[
\frac{\Gamma(K_S \to l^+) + \Gamma(K_S \to l^-)}{\Gamma(K_L \to l^+) + \Gamma(K_L \to l^-)} = 1 + 4\mathbb{R}(c/a) = 1 + 4\mathbb{R}(x)
\]

(14)

To improve the present limits on $\mathbb{R}(x)^{16}$ it is necessary to reach 2% accuracy on the measurement of the $K_S$ semileptonic branching ratio. This will be accomplished by KLOE when the ongoing analysis over the whole data sample will be concluded. Using the same sample, we can also perform the first measurement of the $K_S$ charge asymmetry $A'_s$:

\[
A'_s = \frac{\Gamma(K_S \to l^+) - \Gamma(K_S \to l^-)}{\Gamma(K_L \to l^+) - \Gamma(K_L \to l^-)}
\]

(15)

The precision expected on $A'_s$ is of the order of 1%.

The selection of semileptonic $K_S \to \pi e\nu$ candidate events also starts from the sample tagged by the $K_L$ interactions in the calorimeter: events are selected by requiring two tracks of opposite charge forming a vertex near the IR. A cut on the two track invariant mass is applied to reduce $K_S \to \pi^+\pi^-$ background. Semileptonic events are then identified on the basis of $\pi/e$ assignment using the time-of-flight measurement for the two tracks. The $K_L$ cluster gives an estimate of the $K_S$ momentum, thus allowing the kinematic constraint of the event. The difference between the missing energy and the missing momentum at the vertex is finally computed; such a difference should be zero for $K_S \to \pi e\nu$ decays. The $E_{\text{miss}} - p_{\text{miss}}$ spectrum is shown in Fig. 8, together with a fit to the sum of Monte Carlo simulations of the signal and $K_S \to \pi^+\pi^-$ background. The free parameters of the fit are the signal/background normalization and the signal yield, giving 627±30 events.

Correcting for all the selection and detection efficiencies, and normalizing to the number of observed $K_S \to \pi^+\pi^-$ events, the measured branching ratio is:

\[
\text{BR}(K_S \to \pi^\pm e^\mp \bar{\nu}(\nu)) = (6.91 \pm 0.34_{\text{stat}} \pm 0.15_{\text{syst}}) \times 10^{-4}
\]

in agreement with the expected value $(6.70 \pm 0.07) \times 10^{-4}$ assuming the validity of $\Delta S = \Delta Q$ rule.\textsuperscript{16}
Fig. 8. $K_S$ semileptonic decay: the experimental spectrum for $E_{\text{miss}} - p_{\text{miss}}$ shows a clear peak at zero, corresponding to $K_S \to \pi e\nu$ decays; a maximum likelihood fit with the Monte Carlo signal+background ($K_S \to \pi^+\pi^-$) shapes is superimposed.

4 Physics items under study

Another set of interesting physics measurements is already in advanced stage over the whole data sample. We report them in the following chapters.

4.1 Measurement of the hadronic cross section

The measurement of the hadronic cross section, $\sigma_{\text{had}} = \sigma(e^+e^- \to \text{hadrons})$, at low energy is extremely relevant to improve the theoretical error on the anomalous magnetic moment of the muon, $a_\mu = (g_\mu - 2)/2$. The hadronic contribution, $a_{\mu,\text{had}}$, cannot be calculated at low energy with perturbative QCD while, following a phenomenological approach, can be evaluated from the measurement of $R(s)$ through the following dispersion relation:

$$a_{\mu,\text{had}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^3 \int_{4m^2_\mu} ds \frac{R(s)K(s)}{s^2}, \quad (16)$$

where $R(s)$ is $\sigma(e^+e^- \to \text{hadrons}) / 4\pi \alpha(s)^2$ and $K(s)$ is the kernel. The $1/s^2$ factor in eq. 16 enhances the contribution of $\sigma_{\text{had}}$ at low energy to $a_{\mu,\text{had}}$. The error on $a_{\mu,\text{had}}$ is the dominating contribution to the total theoretical error $a_{\mu,\text{the}}$ and it is related to the
limited knowledge of $\sigma(e^+e^- \rightarrow \text{hadrons})$. The discrepancy between theory and the most recent experimental determination of $a_\mu$ differs depending if $\tau$-lepton data are used or not in evaluating $a_\mu^{\text{had}}$ (from 1.6 to 3.0 standard deviations). This situation pushes for a new precise measurement of $\sigma^{\text{had}}$ at low energy particularly in the $\rho$ region. An accuracy of 0.6% was recently achieved in this region.\textsuperscript{23}

The novelty of the measurement carried out in KLOE is that, even operating at a fixed center of mass energy $\sim M_\phi$, the $\sigma^{\text{had}}$ can be evaluated between the $2\pi$'s threshold and $M_\phi$ using the radiative return, i.e. through the process $e^+e^- \rightarrow \pi^+\pi^-\gamma$. In this process, the emission of photons due to initial state radiation (ISR) lowers the available invariant mass of the hadronic system.

Defining $Q^2$ as the invariant mass of the $\pi^+\pi^-$ system and $\theta_\gamma$ to be the maximum polar angle of the emitted photon used in the analysis, the measured differential cross

Fig. 9. Raw spectrum of the $e^+e^- \rightarrow \pi^+\pi^-\gamma$ events selected with an acceptance cut: $\theta_\gamma$ below 15° and above 165°.
Fig. 10. The form factor $|F_\pi|^2$ as a function of $Q^2$. The curves reported are: the one of the fit described in the text (black) and the one from CMD-2 (grey). They are almost indistinguishable.

section for the process $e^+e^- \rightarrow \pi^+\pi^-\gamma$ is related to $\sigma_{\text{had}}$ as follows:

$$Q^2 \cdot d\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma)/dQ^2 = \sigma(e^+e^- \rightarrow \text{hadrons}) \cdot H(Q^2, \theta_\gamma) \quad (17)$$

A solid theoretical knowledge of the radiator function, $H$, is needed in order to extract $\sigma_{\text{had}}$ from the measured cross section. Different theory groups have calculated these corrections up to next to leading order (NLO) and implemented it in a new MC generator called PHOKHARA. This generator is already used in KLOE, the absolute accuracy claimed is of 0.5%. Compared to the traditional method of the energy scan this technique offers the advantage that the systematics, on both normalization and definition of beam energy, is common to all measured points. However, a precise determination of FSR and other resonance contribution (as for instance $e^+e^- \rightarrow f_0\gamma$) is required.
A more extended report on the KLOE analysis can be found elsewhere, here we recall only the basic analysis steps. The initial sample is selected requiring the presence of two charged tracks coming from IR and produced with polar angles between $40^\circ \div 140^\circ$. A powerful $\pi$-e discrimination is performed using a likelihood method based on time-of-flight and shower shape in the calorimeter. Cutting on the track mass variable $z$ a clear separation between $e^+e^-$, $\mu^+\mu^-$ and $\pi^+\pi^-$ is obtained. A residual background contamination of few % exists at low $Q^2$ values ($< 0.4$ GeV$^2$) from events $\phi \rightarrow \pi^+\pi^-$.$^0$. An acceptance cut on $\theta_\gamma$ define the samples: small-angle ($\theta_\gamma < 15^\circ$) and large-angle ($\theta_\gamma > 45^\circ$).

At the moment, the analysis is focused on the small-angle data sample. Out of the 200 pb$^{-1}$ taken in 2001 and already reconstructed, we have analyzed $\sim 73$ pb$^{-1}$. The $e^+e^- \rightarrow \pi^+\pi^-\gamma$ event yield corresponds to $\sim 15000$ events/pb$^{-1}$. In Fig. 9 the raw spectrum is shown, the $\rho - \omega$ interference is clearly seen, evidence of the excellent momentum resolution of the drift chamber.

Neglecting FSR interference, the pion form factor can be extracted, for each $i$-th bin in $Q^2$, from the observed raw spectrum of $e^+e^- \rightarrow \pi^+\pi^-\gamma$, $N_i^{\text{obs}}$, as follows:

$$|F_\pi(Q_i^2)|^2 = \frac{N_i^{\text{obs}}}{\epsilon(Q_i^2) \cdot L \cdot \sigma_{\text{pl}}(Q_i^2)}, \quad (18)$$

where $\epsilon(Q_i^2)$ is the global efficiency, $L$ is the integrated luminosity and $\sigma_{\text{pl}}(Q_i^2)$ is the differential cross section for $e^+e^- \rightarrow \pi^+\pi^-\gamma$ (see eq. 17) evaluated to NLO and assuming pointlike particles. The systematic error on the efficiency is $\sim 2\%$ while the error on the luminosity and on $\sigma_{\text{pl}}$ is already below the 1% level. The form factor extracted from eq. 18 is shown in Fig.10 and has been fitted following the KS parametrization:

$$F_\pi(Q^2) = \frac{BW_\rho(1 + \alpha BW_\rho)/(1 + \alpha) + \beta BW_{\rho'}}{1 + \beta}, \quad (19)$$

where BW is a standard Breit-Wigner shape. The mass and width of the $\rho$ and the $\alpha$, $\beta$ parameters were left to vary freely on the fit while the other parameters were fixed to the PDG values. Results are in good agreement with what found by CMD-2 although using a slightly different parametrization. As it can be observed in Fig. 10 there is still some residual background to fight at low energies and we have not yet tried a serious unfolding of the experimental resolution. The goal is to publish the form factor with errors below 1%.

$^3$The $M_{\text{trk}}$ variable is obtained applying 4-momentum conservation, under the hypothesis that the final state consists of two particles with same mass and one photon.
4.2 Dynamics of the decay $\phi \rightarrow \pi^+\pi^-\pi^0$

About 15% of the $\phi$ decays proceed to the $\pi^+\pi^-\pi^0$ final state, representing the largest non-kaonic $\phi$ decay. This process is dominated by the $\rho\pi$ intermediate states and, by simple isospin arguments, we expect all the three $\rho$ charged states to be produced with similar rate. This decay is therefore well suited to perform a study of mass or width differences among $\rho^+, \rho^-, \rho^0$. In the literature\cite{26} has also been shown that a direct decay $\phi \rightarrow \pi^+\pi^-\pi^0$ is possible although with a much reduced rate. The published analyses\cite{27,28} from CMD-2 (SND) rely on 12,000 (500,000) events. KLOE reconstructs this kind of events with an overall efficiency of 30% guaranteeing a large data sample with very small contamination. Even when restricting the analysis to 2000 data, a sample of $2 \times 10^6$ events is available to derive the masses and widths of the $\rho$ and the amount of the direct term and its interference with the main $\rho\pi$ term.

The dynamics of the decay is described by the density of the Dalitz-plot. The two
<table>
<thead>
<tr>
<th>$M_\rho$ (MeV)</th>
<th>$\Gamma_\rho$ (MeV)</th>
<th>$\Delta M_{0,\pm}$ (MeV)</th>
<th>$\Delta M_{+,-}$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>775.9 ± 0.6 ± 0.7</td>
<td>145.2 ± 1.2 ± 1.0</td>
<td>-0.5 ± 0.3 ± 0.7</td>
<td>+0.7 ± 0.4 ± 0.7</td>
</tr>
</tbody>
</table>

Table 4. Results on masses and widths of the $\rho$.

<table>
<thead>
<tr>
<th>$\sigma$ (nb)</th>
<th>$a_d$</th>
<th>$\phi_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>470 ± 11</td>
<td>0.093 ± 0.011 ± 0.015</td>
<td>2.45 ± 0.09 ± 0.10</td>
</tr>
</tbody>
</table>

Table 5. Results on cross section and direct term for $\phi \rightarrow \pi^+\pi^-\pi^0$.

standard variables, $X = T^+ - T^-$ and $Y = T^0$, are used, with $T$ being the pion kinetic energy. The accessible phase space is bounded in the almost triangular region as shown in Fig. 11. The density distribution in the Dalitz-plot should reveal the vector nature of the $\phi$-meson. Since the $\pi$’s, produced in the final state, are pseudoscalars the only way to build a vector is by the product of two of the pion momenta (i.e. $\vec{P}_{\pi\pi} = \vec{P}_{\pi^+} \times \vec{P}_{\pi^-}$). The density is then proportional to the square of the amplitude:

$$|A_{tot}|^2 = |\vec{P}_{\pi\pi}|^2 \cdot |\sum A_i|^2,$$

where $A_{tot} = A_{dir} + A_{\rho\pi} + A_{\omega\pi}$. All these amplitudes are complex functions representing the direct term, the main intermediate state $\rho\pi$ and the negligible $\omega\pi$ term. The $\rho\pi$ term is described as the sum of three BW shapes ($k = 0, +, -$ depending upon the charge state of the $\rho$) with a total width which depends on the invariant mass, $Q_k^2$, of the final state $\pi^+\pi^- (\pi^+\pi^0, \pi^-\pi^0)$ as follows:

$$\Gamma_k(Q_k^2) = \Gamma_k(P_\pi(Q^2)/P_\pi(M_k))^3(m_k/Q_k),$$

where $m_k$ are the $\rho$ mass for the three charged states, and $P_\pi$ is the momentum of the pions in their center of mass system. The data shown in Fig. 11 has been fit with eq. 20 after correcting for selection efficiency and integrated luminosity. The results are listed in Tabs. 4, 5 and are still to be considered preliminary since a few checks are in progress on the systematic errors connected to the evaluation of the selection efficiency. At the moment, we summarize the results as follows:

- We do observe a dominant $\rho\pi$ term and definitely established the existence of a direct term with an amplitude of $\sim 9\%$ and a phase of 2.4 rads with respect to the $\rho\pi$ term. This is consistent with the bounds set by CMD-2 which performed a similar analysis.
Fig. 12. Visible cross section for the process $\phi \to K_S K_L$, with $K_S \to \pi^+ \pi^-$, as a function of the center of mass energy, $W$. The fit superimposed is corrected for ISR effects.

- The value of $M_\rho$ is in agreement with PDG, while the value of $\Gamma_\rho$ is slightly lower than PDG which quotes 150 MeV.
- No difference is found, at a per mil level, between $\rho^\pm$ and $\rho^0$, in agreement with the PDG value of $0.4 \pm 0.8$ MeV.
- No difference is found, at a per mil level, between $\rho^+$, $\rho^-$. No entries exists of this measurement in PDG.

### 4.3 A precise determination of the neutral kaon mass

The neutral kaon mass can be measured using the process $\phi \to K_{S,L}$ with $K_S \to \pi^+ \pi^-$ if the $\phi$-mass is used to accurately calibrate the scale of the center of mass energy, $W$. Due to the small mass difference, $\Delta M = (M_\phi - 2M_k) \sim 26$ MeV, it is convenient to express $W$ as a function of kaon quantities:

$$W = E_{K_S} + E_{K_L} \sim 2E_k$$

and

$$M_k^2 = W^2/4 - P_k^2$$
Fig. 13. Comparison of the three most precise measurements of the neutral kaon mass.

in this way we get: $\Delta M_k \sim \delta W/2$. Similarly, the fractional uncertainties on $M_k$ due to a fractional error on $P_k$ is reduced by a factor $\beta_k^2 \sim 0.05$, allowing a high precision mass measurement. For this analysis, we have used the 11 points of the $\phi$-scan performed in 2001 (see Fig. 12). Each collected point consists of $\sim 50 \text{ nb}^{-1}$ of integrated luminosity. The average $W$ value, of each run, is obtained fitting the $e^+e^-$ invariant mass distribution in Bhabha events; relative precision for each point is $\sim 3 \text{ keV}$. The ISR affects the available center of mass energy of an amount which is process dependent; we called $f_k(W)$ the correction for $\phi \rightarrow K_SK_L$ events. In this way for each run, we obtain $W_k = W - f_k(W)$. By measuring the momenta of the kaons and using the average $\phi$ momentum obtained with Bhabha events we get the mass through eq. 23. Single event precision on $M_k$ is around $430 \text{ keV}$.

To calibrate the scale of the center-of-mass energy, we have measured the $\phi$-mass fitting the line shape of the process $e^+e^- \rightarrow \phi \rightarrow K_{S,L}$ with $K_S \rightarrow \pi^+\pi^-$; the fitting function takes into account the ISR and the interference effects of the $\rho$ and $\omega$ mesons with the $\phi$. The only free parameters are the mass and width of the $\phi$ and the peak cross section. The result of the fit is superimposed on data in Fig. 12. We get:

$$M_\phi = (1019.329 \pm 0.011_{\text{stat}}) \text{ MeV}.$$
Fig. 14. Distribution of $M_{\gamma\gamma}$ for the events with a $K_L$ tag and two photons connected to the neutral vertex.

The value found, with a similar fitting procedure, by the CMD-2 experiment is instead:

$$M_{\phi} = (1019.504 \pm 0.011_{\text{stat}} \pm 0.033_{\text{syst}}) \text{ MeV}.$$ 

In this case the energy scale is measured using the resonance depolarization method. Comparing the two values we get a $W$-scale correction factor of 1.00017 (i.e. a mass shift of around 170 keV). The average value of the kaon mass obtained is:

$$M_K = (497.584 \pm 0.005_{\text{stat}}) \text{ MeV}.$$ 

Small contributions to the systematic error on $M_K$ are given by the momentum scale (6 keV) and by the $f_k(W)$ correction (7 keV); the dominant contribution is still due to the determination of the energy scale which corresponds to $\sim 18$ keV. In Fig. 13, a comparison between our result and other measurements of the kaon mass is shown.

### 4.4 BR measurement of the $K_L \to \gamma\gamma$ decay

Although still statistically limited, there are interesting physics topics also in rare $K_L$ decays. At present, we are carrying out a precise measurement of the BR($K_L \to \gamma\gamma$)
Fig. 15. Distribution of $\tau_K$ for the $K_L$ events with more than three photons connected to the neutral vertex.

since its value is a good test for Chiral Perturbation Theory predictions. This decay is very precisely measured by NA48 through the ratio $R_{2\gamma,3\pi^0}$:

$$R_{2\gamma,3\pi^0} = \frac{BR(K_L \to \gamma\gamma)}{BR(K_L \to \pi^0\pi^0\pi^0)} = (2.81 \pm 0.01_{\text{stat}} \pm 0.02_{\text{syst}}) \times 10^{-3}. \quad (24)$$

In our search, we first select a $K_L$ tagged-sample requiring a $K_S \to \pi^+\pi^-$ decay. We then reconstruct the neutral vertex connected to the $K_L$, NV, using the position and timing of the neutral clusters, NC, associated to this vertex and the knowledge of the $K_L$ flight direction provided by the $K_L$ tag. At the end of this procedure, a spatial resolution of $\sim 1/2$ cm on NV is obtained. We retain for further analysis the events having only two photons connected to NV. After few topological cuts are applied, and plotting the invariant mass of the two photons, a clean peak at the $K_L$ mass (see Fig. 14) is observed. The background is small and is concentrated at low mass values ($M_{\gamma\gamma} < 400$ MeV). The signal/background ratio obtained integrating over the whole spectrum is 12. In a sample of 150 pb$^{-1}$ we count $8537 \pm 117$ events. Normalization is performed with the $K_L \to 3\pi^0$ events counted in the same sample. They are obtained with the same technique counting all the events with NC $\geq 3$. The resulting ratio $R_{2\gamma,3\pi^0}$ is:

$$R_{2\gamma,3\pi^0} = (2.84 \pm 0.04 \pm 0.03) \times 10^{-3} \quad (25)$$
At present, we are analyzing all available statistics and working on reducing the systematic errors. Using the normalization sample of $K_L \rightarrow 3 \pi^0$ we have also measured the lifetime of the $K_L$ as reported in Fig. 15.

### 4.5 Physics reach with charged kaons

Similarly to the $K_SK_L$ pair, the $\phi$-meson decays 49% of the time into a $K^+K^-$ which corresponds to a $K^\pm$ production rate of $1.5 \times 10^6 / \text{pb}^{-1}$. At the moment, we have collected $0.8 \times 10^9 K^+K^-$. Also for this process, a unique feature of KLOE is tagging i.e. observing a $K^+(K^-)$ in one side of the detector allows to establish the direction and the presence of the $K^-(K^+)$ in the opposite hemisphere. Given the available rates, we can measure with high accuracy the production cross section and all the decay branching ratios of the charged kaons.

One interesting measurement which is being carried out is the determination of $|V_{us}|$ from $K_{l3}$ decays: $K^\pm \rightarrow \pi^0 l^\pm \nu$ called $K_{l3}^+$ and $K^0 \rightarrow \pi^\pm \mu^\mp \nu$ called $K_{l3}^0$ where $l$ stands either for electron or muon. The most accurate test of the unitarity condition, on the CKM-matrix, is provided by the measurements of $|V_{us}|, |V_{ud}|$ and $|V_{ub}|$ matrix elements; present experimental value indicates a $(1.0 \div 2.7) \sigma$ effect of deviation from unitarity.$^5$

The partial width of a generic $K_{l3}$ decay$^{31}$ is given by:

$$\Gamma(K_{l3}) = \frac{G_F^2 M_K^5}{192 \pi^3} \cdot S_{EW} \cdot C_K^2 |V_{us} \cdot f_+(0)|^2 \cdot I_K(m_K^2, m_\pi^2, m_l^2, f_{+,0}(q^2)) \times (1 + \delta_k), \quad (26)$$

where $G_F$ is the Fermi constant, $I_K$ is the phase-space integral and $f_+(q^2), f_{0}(q^2)$ are the form factors of hadronic vector current with change of strangeness. These form factors incorporate also the isospin breaking correction (between $K^\pm, K^0$) and the second order SU(3) breaking effect arising from $s-d, u$ quark mass difference. Radiative corrections are factorized in the two terms $S_{EW}$ (electroweak short-distance correction) and $\delta_k$ (QED long distance correction). The width, $\Gamma(K_{l3})$, is usually measured as $\text{BR}(K_{l3}) \times \Gamma_K$.

Measuring also the $q^2$ dependence of the form factor:

$$f_{+,0}(q^2) = f_{+,0}(0) \cdot \left(1 + \frac{\lambda_{+,0}}{m_\pi^2} q^2 \right), \quad (27)$$

the integral $I_K$ can be evaluated leaving as the basic observable the product $|V_{us} \cdot f_+(0)|$.

The form factor at $q^2 = 0$ is determined by theory and it is the dominant (0.86%) contribution to the error on $|V_{us}|$. The determination of $V_{us}$ from $K_{l3}$ decays$^5$ corresponds
to: \( V_{us} = 0.2196 \pm 0.0026 \) (1.18% relative error). The errors on the measurement can be parametrized as:

\[
\frac{\Delta|V_{us}|}{|V_{us}|} = \left[ 0.5 \times \left( \frac{\Delta \text{BR}}{\text{BR}} \oplus \frac{\Delta \tau_k}{\tau_k} \right) \oplus \left( 0.05 \times \frac{\Delta \lambda_+}{\lambda_+} \right) \oplus \left( \frac{\Delta f_+(0)}{f_+(0)} \right) \right],
\]

(28)

where \( \tau_k \) is the \( K \) meson lifetime. Aside from the theoretical error on \( f_+(0) \), there is also a 0.6% error on the BR measurements (still driven by \( K_{e3} \) decays). As explained above, the measurement in both \( K_{e3}^+ \) and \( K_{e3}^0 \) events allows one to test the current understanding on SU(2), SU(3) breaking effects and a new measurement of BR for both \( K_{e3}^+ \) and \( K_{e3}^0 \) is necessary. This is also a strong motivation to determine these values in the same experiment.

The strategy for the measurement of \( \text{BR}(K_{e3}^+) \) is to use the very clean signature of the decays \( K^\pm \to \pi^\pm\pi^0 \) and \( K^\pm \to \mu\nu \) to tag the other charged kaon in the event. The tagging efficiency is estimated directly on data using for instance, the redundant calorimetric information. From the statistical point of view, we expect to reach a relative error on the BR below 0.1% using the whole available statistics.

## 5 Future prospects

Many other physics topics are being carried out by the collaboration and, although in a very preliminary state to discuss publicly, it is interesting to list the work in progress to show the physics reach of the experiment. As far as the hadronic physics is concerned, the factor 30 increase in statistics will allow us to:

- perform an exhaustive study of the \( f_0(980), a_0(980), \eta' \) mesons with a factor 5 reduction on the relative statistical error. In the meanwhile working on the systematics side we expect to reach:
  1. \( \sim 1\text{-}2\% \) precision on the BR for the processes \( \phi \to f_0\gamma, \phi \to a_0\gamma \);
  2. \( \sim 3\% \) precision on the BR for the process \( \phi \to \eta'\gamma \) and a stringent limit on gluonium content;
- look for the interference scheme between the \( f_0(980) \) and the final state radiation in \( e^+e^- \to \pi^+\pi^-\gamma \) at large photon polar angles;
- start the study of rare physics in the \( \eta \) sector. We have at the moment \( \sim 5 \times 10^6 \) \( \eta \)'s. We expect to set upper limits on rare C-violating decays such as \( \eta \to \gamma\gamma\gamma \). The high statistics sample will also permit to measure the Dalitz-plot slopes of the decay \( \eta \to \pi^0\pi^0\pi^0 \) and \( \eta \to \pi^+\pi^-\pi^0 \).
In the kaon sector we intend to do the following:

- using the semileptonic decay of the $K_S$ we can perform a test of the $\Delta S = \Delta Q$ rule and measure with 1% precision the charge asymmetry;
- improve the precision in the determination of $R_\pi$ to 0.1% while showing also for the first time the differential decay rate for $K_S \rightarrow \pi^+\pi^- (\gamma)$ as a function of $E_\gamma$;
- measure the BR of the CP violating decay of the $K_L$ (e.g. to $\pi^0\pi^0, \pi^+\pi^-$) with around 1% precision;
- measure all single $K_L$ decay to better than 1%;
- start the search on rare $K_S$ decays (e.g. $K_S\rightarrow\pi^0\pi^0\pi^0, K_S\rightarrow\pi^+\pi^-\pi^0$);
- measure the incoherent regeneration cross section of $K_L$ on Be/C; the boost of the $\phi$ meson originates also a $\sim 10$ MeV spread in the kaon momenta permitting to perform this measurement also as a function of $P_K$;
- Although with limited statistics, the quantum interferometry scheme is being observed in the $\phi \rightarrow K_SK_L \rightarrow \pi^+\pi^-\pi^+\pi^-$ channel. The intention is to show this and all the other interferometry effects.

On the $\phi$ sector we expect to measure to better than 1% all main decay channels of the $\phi$ meson while performing also the measurement of $\Gamma_{ee}$ and $\Gamma_{\mu\mu}$.

### 6 Conclusions

DAΦNE performance has improved considerably after the first two years of data taking delivering now a luminosity of $> 3.5 \text{ pb}^{-1}$ per day in the KLOE interaction region. A long winter shutdown is scheduled to roll-in the FINUDA detector in the opposite interaction region while installing a new interaction region in KLOE. The goal is to reach a peak luminosity of $5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ in order to start CP-CPT studies in the 2003-2004 data-taking periods.

The KLOE detector is fully operational and reconstruction details are well understood. From the small sample of the 2000 data taking, we have results on $K_S$ and $\phi$ radiative decays which improve the previous PDG values. At the moment, the reconstruction of data summary tapes for all data collected up to now is completed and the analysis is started on the whole statistics: new results are expected on rare $K_S, K_L$ decays and on many items of charged kaons, $\eta, \eta', \rho, a_0$ and $f_0$ mesons. We also expect to publish a very precise measurement of the hadronic cross section at low energies.
7 Acknowledgments

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