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# A PROPOSAL FOR THE ROLL-IN OF THE KLOE-2 DETECTOR

The KLOE-2 Collaboration

## Abstract

This is a proposal for a multi-step installation of the KLOE-2 detector on the DAΦNE beam line, starting from the fall of 2008.

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# 1 Introduction

This is a proposal for a multi-step installation of the KLOE-2 detector on the DA$\Phi$NE beam line, starting from the fall of 2008.

The LNF Accelerator Division (LNF-DA) is currently committed to finalizing the design and preparing the new interaction region, based on the *crabbed waist* scheme [1], to increase the collider luminosity up to an order of magnitude. The upgraded machine is scheduled to start operations by the end of 2007, delivering beam to the SIDDHARTA experiment. The SIDDHARTA program should be finished by June 2008. At that time, the potentiality of the beam-interaction scheme proposed by the LNF-DA for running the $\phi$-factory above $10^{33}$ cm$^{-2}$ s$^{-1}$, should be well settled.

We propose to prepare the interaction region for the KLOE-2 roll-in at the end of 2008. At that time, the KLOE apparatus with minimal upgrades, required to operate a fully efficient detector (*phase 0*), will be ready for data taking. This phase will be followed by the installation of the more complex detector upgrades (*phase 1*), mostly for improving the tracking and clustering capabilities of the experiment in view of a longer data taking campaign. Further installation steps could also be envisaged in the future, depending on the performance of the machine, and on physics results.

Resuming data taking as early as next year, will have several advantages. It will allow us to increase significantly during the course of 2009 the present KLOE data sample and therefore the sensitivity of the measurements described in the *Expression of Interest* presented in March 2006 [2]. It will allow the optimization of the accelerator performance. Some tuning is also required from the presence of the KLOE solenoidal field and by KLOE's need of studying background levels induced in the detector.

In the next section we will summarize our plan, specifying the technical work we intend to perform at the two proposed steps, as well as their main physics potentials. Details will be given in the rest of the paper.

# 2 KLOE-2 Roll-in proposal

## 2.1 Step 0

We plan to perform the Step 0 installation soon after the end of the SIDDHARTA run, i.e. by the fall of 2008, provided that the machine is able to deliver a luminosity that is at least 3 times the one delivered to KLOE at the end of 2005.

Step 0 consists of:

1. Insertion of the new interaction region inside KLOE

2. Installation of the new DAQ components: Level-2 (L2) and Level-3 (L3) CPUS, run-control (RC) and slow-control servers, optical Gigabit Ethernet link for L2 to RC connection
3. Production of the minimal set of FEE spares, necessary for a safe and efficient run
4. Upgrade of the Computing System, to cope with the larger data set
5. Installation of the outer pair of $\gamma\gamma$-taggers (HET)

In one year of data taking, we will integrate a luminosity $\geq$5 fb$^{-1}$. With this, we can

1. Improve on $K_{l3}, K_{\mu 2}$, for lepton universality and $V_{us}$
2. Set the best limits on several QM-$CPT$-violating parameters
3. Improve on the measurement of $K_{e2}$ decays down to few per mil, thus testing LFV at this level
4. Improve on several $K_S$, $\eta$ and $\eta$' rare decays
5. Observe for the first time $f_0, a_0 \to K\overline{K}$ decays
6. Measure the part of the invariant mass spectrum of the reaction $e^+e^- \to e^+e^-\pi\pi$ relevant for Chiral Perturbation Theory studies

## 2.2 Step 1

At step 1, we will be ready for more complex installations, namely:

1. Installation of the Inner Tracker
2. Implementation of the new e.m. calorimeter readout scheme
3. Installation of the newly proposed forward photon vetos and new QCALs
4. Installation of the inner pair of the $\gamma\gamma$ taggers
5. Further upgrades of the Computing and FEE, according to physics requests and technical opportunities

At this level, we will expect to realize all the physics potentials of KLOE-2 as explained in our EoI. We will gain both on systematics, thanks to a better detector, and on statistics, thanks to an integrated luminosity $\geq$ 20 fb$^{-1}$. Thus we will:

1. Set the ultimate limits on QM-$CPT$-violating parameters
2. Measure the $K_{e2}$ decay rate with a precision of $\sim$0.1$\%$
3. Reach a sensitivity of few parts in ten thousand in the measurement of $\mathrm{Re}\,(\epsilon'/\epsilon)$
4. Measure the $CP$-violating plane asymmetry in the decays $\eta \to e^+e^-\pi^+\pi^-$ down to the per mil level
5. Observe for the first time $K_S \to 3\pi^0$ decays
6. Further improve on the above mentioned $K_S$, $\eta$ and $\eta$' rare decays

## 3 KLOE-2: Physics motivations

An extensive discussion of the KLOE-2 physics program can be found in [2]. At the $\phi(1020)$ peak [1] it can be seen as the continuation of the KLOE program, whose results (based on an acquired luminosity of 2.5 fb$^{-1}$) can be largely improved by both the increased data sample and the proposed detector upgrades. A short list of topics follows.

### 3.1 Quantum Interferometry and CPT tests

$CPT$ invariance is a fundamental theorem in the framework of quantum field theory (QFT), as a consequence of Lorenz invariance, unitarity and locality. In several quantum gravity (QG) models, however, $CPT$ can be violated via some mechanism which can also violate standard Quantum Mechanics (QM). In a recent review Bernabeu, Ellis, Mavromatos, Nanopoulos and Papavassiliou [3] discuss the theoretical motivations for possible $CPT$ violations and the unique role played by the entagled neutral kaon pairs produced at DAΦNE in precision tests of the $CPT$ symmetry.

As an example of this incredible precision reachable with neutral kaons, we take the model by Ellis, Hagelin, Nanopoulos and Srednicki (EHNS) which introduces three $CPT$ and QM-violating real parameters $\alpha$ $\beta$ and $\gamma$ [4]. On phenomenological grounds, they are expected to be $O(m_K^2/M_{Pl})$ $\sim$2$\times$10$^{-20}$GeV at most, since $M_{Pl}$ $\sim$10$^{19}$ GeV, the Plank mass. Interestingly enough, this model give rise to observable effects in the behaviour of entagled neutral meson systems, as shown also in [5], that can be experimentally tested.

KLOE has already published competitive results on these issues [6], based on a statistics of $\sim$400 pb$^{-1}$, and is now on the way of updating them using the full data sample. The analysis makes use of correlated $K_L^0 - K_S^0$ pairs, by measuring the relative distance of their decay point into two charged pions. The decay region most sensitive to the EHNS parameters is the one close to the IP.

Figure 1 shows the potential limits that can be obtained by KLOE on $\alpha$, $\beta$, and $\gamma$ as a function of the integrated luminosity, both with and without the insertion of an inner tracker with vertex resolution of 0.25 $\tau_S$ (to be compared with the present KLOE vertex resolution, 0.9 $\tau_S$). In the figure also are given the results from CPLEAR [7]. Without entering too much into the details, it is clear that with a reasonable integrated luminosity, KLOE-2 can set the best limits on these parameters. Moreover, the more interesting region below the Plank limit of 2$\times$10$^{-20}$ GeV can be explored also for the parameter $\beta$ as soon as $\int Ldt \geq$ 5-10 fb$^{-1}$.

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[1] We have proposed also the use of the KLOE-2 detector for physics at a c.m. energy ranging between 1 and 2.4 GeV. The present document, however, is focused on the operation of the collider at the $\phi$ peak planned for the near future.

### 3.2 $CP$ Violation

The study of $CP$ violation in kaon decays has been the main motivation for the construction of KLOE and DAΦNE. The aimed precision on $\mathrm{Re}\,(\epsilon'/\epsilon)$ of a few parts in ten thousand was not achieved because of statistical limitation. At the new machine, this can be obtained both via the measurement of the four separate branchig ratios and via interferometry (which allows also the measurement of $\mathrm{Im}\,(\epsilon'/\epsilon)$).

Concerning the first technique, it is important to remember that KLOE has already measured the ratio of the charged to neutral two-pion decays of the $K_S^0$ with a precision of 0.2$\%$ [8]. Moreover, BR$(K_L^0 \to \pi^+\pi^-)$ has been measured with a precision of $1\%$, using $\sim$1/5 of the acquired statistics [9]. Taking into account the 1/6 factor in the double ratio formula, the key missing ingredient for the measurement of $\mathrm{Re}\,(\epsilon'/\epsilon)$ is BR$(K_L^0 \to \pi^0\pi^0)$ for which one can obtain an accuracy of few per mil with an integral luminosity $\geq$10 fb$^{-1}$.

A direct consequence of $CP$ violation in the kaon sector is the prediction BR$(K_S^0 \to 3\pi^0) \sim 2\times10^{-9}$. This decay has however never been observed. The best limit comes from KLOE BR$(K_S^0 \to 3\pi^0) < 1.2 \times 10^{-7}$, based on a statistics of $\sim$400 pb$^{-1}$ [10]. Here the main problem is the rejection of the background produced by the $CP$-allowed two pion decays with additional spurious neutral clusters in the event, a problem which becomes more and more severe with increasing luminosity. A study performed on the entire KLOE data sample, however, shows that background levels can be kept under control, without loosing too much in signal efficiency so that the previously quoted limit can be scaled almost linearly with luminosity, at least for $\int Ldt \leq$ 5-10 fb$^{-1}$. Moreover, the proposed insertion of a low-theta photon veto (see later) would increase acceptance for this very rare decay.

It has been argued [11] that some unconventional $CP$-violation mechanism could induce an angular asymmetry of the production plane of the $e^+e^-$ pair with respect to that of the $\pi^+\pi^-$ pair, for the decay $\eta \to e^+e^-\pi^+\pi^-$. This asymmetry, $A_\eta$, can be as large as $\sim$1$\%$, while in the Standard Model it is negligible. KLOE has started an analysis of this decay channel, with very promising results. A signal of several hundreds events is clearly seen in a subsample of about 600 pb$^{-1}$, to be compared with the two previous measurements, which are based on 7 and 16 events[12]. With the present KLOE statistics a sensitivity on $A_\eta$ of order few per cent can be reached. It has to be underlined that, due to the low average momentum of the four tracks, acceptance in this case is a key issue. The insertion of the inner tracker would therefore be extremely beneficial, and would allow us to reach a sensitivity down to the per mil level.

### 3.3 Other Discrete Symmetry Tests

$P$ and $C$ are believed to be exact symmetries of strong and electromagnetic interactions. Tests of their validity have been published by KLOE by setting the limits BR$(\eta \to \pi^+\pi^-) < 1.3 \times 10^{-5}$ and BR$(\eta \to 3\gamma) < 1.6 \times 10^{-5}$, on the basis of ~400 pb$^{-1}$ of data [13], [14]. The previous limits can be taken down to the $10^{-7}$ level, which would be among the best limits on $P$ and $C$ conservation ever set in elementary particle decays [15]. It is worth noting that for the first decay channel the experimental improvements are expected to come mainly from the increase in luminosity, while in the second case an additional handle can come from the insertion of the low-theta gamma vetos.

Further tests of $C$ invariance can also be performed using the decays $\eta \to \pi^0\pi^0\gamma$, $\eta \to \pi^0 e^+e^-$, $\eta \to \pi^0\mu^+\mu^-$.

### 3.4 Precise measurement of $V_{us}$

In the recent years, flavor physics and in particular the precise determination of the CKM matrix elements has received great attention. Deviations from unitarity of the CKM matrix would signal presence of physics beyond the Standard Model. The test of unitarity of the first row of the CKM matrix reads:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = (0.9737 \pm 0.0003)^2 + (0.2255 \pm 0.0013)^2 + 0(10^{-5}) \quad (1)$$

where the value of $V_{us}$ is largely dominated by KLOE results. KLOE is in fact the experiment that has provided the most experimental inputs for this determination: branching ratios, lifetimes, form factors [16], [17].

From the inspection of the above equation, it is clear that a more precise test of unitarity requires a measurement of $V_{us}$ at the per mil level. At present the largest uncertainty on $V_{us}$ comes from the error on the theoretical calculation of $f_+(0)$, the kaon form factor at zero momentum transfer, which is known with a precision of 0.5$\%$ . Recent progress of lattice QCD, however, suggest the possibility that this error can be soon reduced by a considerable factor, moving therefore the attention to the experimental side.

KLOE-2 is natural for performing these precision experiments. For instance, we could easily improve on the measurement of the $K_L^0$ and $K^\pm$ lifetimes. Also, we can precisely measure the $K_S^0$ semileptonic decays. KLOE has published the best determination of this branching ratio [17] BR$(K_S^0 \to \pi e \nu) = (7.046 \pm 0.091) \cdot 10^{-4}$, based on 400 pb$^{-1}$ of data. Most of the systematics scale with statistics, thus one can expect this branching ratio to be determined with a precision approximately scaling with the square root of luminosity, reaching the 0.2$\%$ level at around 20 fb$^{-1}$. The advantage here, with respect to the use of the more copious semileptonic $K_L^0$ decays, is that the $K_S^0$ lifetime is already known with a precision of a few parts in ten thousands.

### 3.5 Lepton Flavor Violation

In the Standard Model, the ratio $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ can be calculated with great accuracy. We have

$$R_K^{SM} = (2.472 \pm 0.001) \times 10^{-5} \tag{2}$$

In a SUSY framework, however, violations of lepton universality can be expected in $K_{l2}$ decays, inducing deviations from the prediction above at the level of up to few per mil[18].

Experimental knowledge of $R_K$ has been poor so far. Recently, however, the NA48/2 Collaboration has presented results based on two separate samples of about 4000 observed $K_{e2}$ events each and has planned a data taking campaign for the summer 2007 with the goal of obtaining a precision on $R_K$ of few parts in a thousand. Also KLOE has presented a preliminary result, based on about 8000 events, obtained analyzing a large fraction of the acquired statistics. Both the KLOE and the NA48/2 result confirm the SM at the percent level.

The KLOE result demonstrates the capability of KLOE-2 of reaching a precision comparable to the one foreseen for NA48/2, with an integrated luminosity of $\geq$20 fb$^{-1}$. This is extremely relevant, since the two experiments have totally different systematics.

### 3.6 Low energy QCD

There still exists no analytical method for the description of QCD at low energy. However, new techinques have been developed to systematically perform QCD inspired calculations on the strong and electromagnetic interactions of the pseudoscalar meson, in the framework of an effective theory, the Chiral Perturbation Theory (ChPT) [19]. Such a theory is based on a perturbative expansion in terms of the momenta of the involved mesons. The price to pay is the rapid increase in the number of free parameters, to be determined experimentally, as the perturbative order increases.

At present, calculations are being done up to the order p$^4$, and the question arises on what can be the contribution coming from the next-to leading order corrections. This issue can be addressed experimentally, by precision measurements of several $K, \eta$ and $\eta$' decay channels, most of which are at present controversial.

For instance, KLOE has measured BR($K_S^0 \to \gamma\gamma$) = (2.27$\pm$0.13$^{+0.03}_{-0.04}$) $\times 10^{-6}$, a result which differs by more than three sigmas from NA48 and is in perfect agreement with $O(p^4)$ ChPT expectations (see figure 2). However, this measurement is limited by statistics and by the presence of a large background of $K_S^0 \to 2\pi^0$ events with two lost photons. A large improvement on background rejection (almost a factor three ) is expected by building a dedicated photon-veto detector in the low-$\theta$ region, down to 8-10°. Analogous improvement is foreseen also for the $\eta \to \pi^0\gamma\gamma$ decay. This last decay is particularly interesting since in ChPT all lower level contributions are suppressed, so that it provides a window for $O(p^6)$ effects. Recent results from Crystal Ball and KLOE are in good agreement with ChPT, however the $M_{\gamma\gamma}$ spectrum, which is of interest for the theory, has never been measured, because of the large background coming from $\eta \to 3\pi^0$ decays. In this case any sizeable improvement in cluster reconstruction, obtained also by the upgrade of the EmC readout, has an impact on the final sensitivity.

### 3.7 Studies on the nature of the Scalar Mesons

The nature of the lowest mass scalar mesons is a long standing question. On the one hand, evidence of the lowest mass states is still experimentally weak, on the other the very important issue of the $s$-quark content of the $\mathrm{f}_0$ and $\mathrm{a}_0$ is not fully understood. This latter point has been widely investigated by KLOE, using the radiative decays $\phi \to \pi^+\pi^-\gamma, \pi^0\pi^0\gamma, \eta\pi^0\gamma$ [20]. In this case, however, the couplings of the two mesons with kaons ($g_{fkk}$, $g_{akk}$), have to be determined indirectly, using some phenomenological model. A more direct measurement of these two couplings can be done searching for the much rarer decay chains $\phi \to (f_0, a_0)\gamma \to K\overline{K}\gamma$.

KLOE has searched for these decays, setting the preliminary limit $B(f_0, a_0 \to K\overline{K}) < 1.8\times10^{-8}$. This limit is at the border of where one could reasonably expect to see the signal (see figure 3) and start making sensible statements about $g_{fkk}$ and $g_{akk}$. It is therefore of utmost importance to increase the data sample as much as planned in the *phase 0* of the experiment.

The radiative decays $\phi \to \pi\pi\gamma$ have also been used by KLOE to search for the $\sigma$ meson. While its existence is required in the framework of the Kaon-loop model to obtain a good fit of the KLOE data for the neutral channel, the ISR background to the charged decay mode makes the $\mathrm{M}_{\pi\pi}$ spectrum quite insensitive to this term, i.e. the quality of the fit to the invariant mass distribution does not change by the addition of the $\sigma$ contribution. Experimental evidence of the $\sigma$ has however increased in the recent years. It has been shown [23] that the $\pi\pi$ scattering amplitude contains a pole with the quantum numbers of the vacuum with a mass of $M_\sigma = 441^{+16}_{-8}$ MeV and a width of $\Gamma_\sigma = 544^{+25}_{-18}$MeV.

The $\sigma$ case could be definetively solved by studying the process $\gamma\gamma \to \pi^0\pi^0$ at low energies, for which theoretical predictions exists based on Chiral Perturbation Theory to two-loop acccuracy [21]. An evaluation of the invariant mass ($\mathrm{M}_{\gamma\gamma}$) distribution for the process $\gamma\gamma \to \pi^0\pi^0$, assuming that the $\sigma$ resonance is produced in the $\gamma$-fusion channel, has also been done [24]. The line shape of the cross section has been shown to be sensitive to the presence of the $\sigma$ meson.

Unfortunately, the only available experimental information on this channel in the region of interest [25] is relatively poor, and do not allow to draw any conclusion about the agreement with either the ChPT calculations nor on the existence of the broad (250-500 MeV) $\sigma(500)$ resonance.

## 4 The KLOE-2 detector

In 7 years of operation at DAΦNE, KLOE has proven to be an efficient and highly reliable detector. The fraction of inefficient channels has always been kept at the percent level. The DAQ system was run routinely by physicists, who also monitored the quality of the data by means of an efficient and user friendly control system. Data were processed quasi-online, giving feedback on the status of the data taking. The quality of the acquired data was excellent.

For the above reasons, the design of the KLOE-2 detector has been driven by the goal of using as much of the KLOE apparatus as possible. On the other hand, some upgrade of the front-end, readout and trigger electronics is mandatory, due to lack of spares and normal obsolescence of componenents. Also the computing system needs to be upgraded, in view of the larger amount of data and the need of replacing old and/or out-of-the-market components. Furthermore, physics driven considerations on some of the above mentioned physics channels suggest some relatively major modification and/or the installation of new hardware in the apparatus.

Most of this has been already described with some detail in our Espression of Interest [2]; here, we will just give emphasis to the progress made on each item in the last year, together with a reasonable time table for its final implementation.

For the sake of clarity, in this paper we have divided the proposed interventions in two distinct categories, those aiming at the full functionality of the KLOE apparatus, mandatory for the *phase 0* of the experiment, and the realization of new devices.

## 5 Minimal Upgrades

### 5.1 Interaction Region

The design of the new interaction region (IR) differs from the KLOE one, in several respects. The low-$\beta$ quads are different and closer to the interaction point; the two beam lines are split *inside* the KLOE region. The hole in the endplates of KLOE, which presently allows the beam line to come out from the apparatus, might need to be modified.

Although some conceptual design exists, real technical work has still to be started. It has to be carried out in close collaboration with the DA. At present the relevant experts of the DA are fully committed to the preparation of the SIDDHARTA run. We have therefore planned to start working on this problem soon after the installation of SIDDHARTA, i.e. in the fall of 2007.

A very important issue is that the design has to be studied in view of the installation of the new hardware (inner tracker, new QCALs, photon veto, gamma-gamma tagger) which has to be inserted very close to the IR (see later).

### 5.2 FEE and Trigger

The KLOE FEE and trigger electronics has been designed and built more than 10 years ago; most of the components are obsolete and not all the devices have enough working spares. For this reason, a first run can safely start only after short term maintenance has been performed. This implies the acquisition of some obsolete componenents, to be used for repairing some broken spare. For this purpose, the dedicated electronics test-stand, at the third floor of the KLOE building has to be reactivated.

A special care has to be devoted to the Trigger system. It is made of 11 different types of boards, specifically built for KLOE needs, most of which are installed in very few replicas on the apparatus. New spare boards need to be produced. A longer term project is the design and implementation of a new and different DC trigger system. We intend to replace the present one which might not be flexible enough to work in a different (lower) magnetic field. Work on this issue has already started in Uppsala. It is likely that the new system will not be installed at *phase 0*, but it could require modifications to the DC on detector electronics that can be implemented at that time.

### 5.3 DAQ

In the KLOE DAQ architecture, information is collected by 10 FEE readout chains, each managed by a Level 2 (L2) commercial CPU which transfers data to the event builders which are managed by L3 computers. The L2 CPUs are also used at run initialization to properly configure the readout. The data communication system is programmed using the standard TCP/IP protocol stack and the hardware network link layer is FDDI. The networking hardware is the FDDI Gigaswitch.

This DAQ system has shown a very high degree of reliability during the long years of KLOE data taking and also showed a remarkable degree of scalability as higher data flows have been managed by simply adding more L3 machines to the DAQ configuration. Also, the FDDI link speed (100 Mbps per chain) has never been a bottleneck for KLOE DAQ data rates and the full system has been tested well beyond the DAQ design limits.

Since L3 machines are 4-way SMP processors each machine has run efficiently multiple independent processes including CPU-intensive T3 filters and various processes for run-time data sampling and run-time data-quality analyses. L3 machines have also been used for short-term data storage (1 day maximum) and export of data to the reconstruction farms (and to the long-term storage chain).

Within this environment, an increase of the collider luminosity of a factor between

3 and 10 should only require more L3 machines (larger data flows and more run-time filtering) while an upgraded detector, should only require a somewhat larger amount of L2 CPUs (more readout chains) and no other major modifications.

From the hardware point of view, this ideal scaling behavior is not possible because of the obsolescence of harwdware components, no maintenanance or support is presently available at both hardware and software levels.

The upgrade of the hardware of the KLOE DAQ Systems is a much needed step and requires that FDDI networking be substituted by optical Gigabit Ethernet where optical links are a mandatory requirement which is dictated by the need of electrical isolation of the KLOE detector. The optical cabling used for KLOE is compatible and can be reused.

This much needed networking change, namely from FDDI to Gigabit Ethernet, also calls for other changes at almost all levels of the DAQ system. These changes include:

1. a new optical Gigabit switch (most easily obtained, at least initially, using some refurbished components, plugged inside the present KLOE CISCO switch)
2. all L2 CPUs, replaced with modern and faster, Gigabit Ethernet, VME CPUs
3. all L3 machines, replaced with similar and much faster 4-way SMP processors for improved filtering
4. also other service machines should be replaced such as run control, online calibration

All hardware changes that have been discussed above are not expected to require extensive software changes as the networking protocol is TCP/IP which will not change. However, it is expected that some tuning and extensive experimentation will be required as experience has shown that even portable software does indeed require tuning, at least because of the higher speed of the hardware.

## 6 Installation of new hardware

### 6.1 The Inner Tracker

The first hit measured by the KLOE Drift Chamber (DC) is at a radius of 28 cm from the IP. The insertion of an Inner Tracker (IT) would be beneficial both for the reconstruction of $K^0_S$, $K^0_L$ and $K^\pm$ decays near the IP, and for increasing the acceptance of low momentum tracks from $K^0_S$ and $\eta$ decays.

One of the key issues for the construction of the IT is the need for keeping the material budget as low as possible, $\sim$1-2$\%$ X$_0$. For this reason we have chosen to make use of a new technique, the cylindrical-GEM (CGEM) developed at LNF.

A description of this device can be found elsewhere. In brief, it will consist of five concentric cylinders, about 50 cm long, located between the beam pipe and the DC inner wall. Each cylinder is a triple-GEM detector of the type of those built for the LHCb experiment, which have however a planar geometry. The real challenge of this solution is in fact the possibility of operating the GEMs in such a new shape.

At present we have built a small size prototype, with which we have succesfully tested the basic functionalities of the device, and are constructing a 1:1 prototype of the first layer of the final detector, to be tested with cosmic rays and at a test beam facility by the fall of 2007.

A dedicated effort is being devoted also to developing a custom readout chip. The main features of this readout ASIC will be the low power dissipation and low input equivalent noise in the detector capacitance range ($0-50$ pF).

In detail the single channel architecture is made of four different blocks: a charge sensitive preamplifier, an amplifier-shaper a discriminator and a monostable. The charge sensitive preamplifier integrates the input current signal from strips into a voltage. The amplifier-shaper provides noise filtering and semi-gaussian shaping. The discriminator generates the digital tracking information and, finally, the monostable will stretch the digital signal to allow for L1 trigger generation. The digital section, besides the control logic for threshold sensing/setting manages the discriminated signal serialization for data RO. No free running clock is foreseen in the front-end board to avoid (possible) cross-talk in the analog section. The RO procedure will start only after a L1 trigger validation signal. The modularity has been set to 64 channels.

A first version of the chip has already been designed. The device includes 16 channels and the full digital chain. Some prototypes are expected to be delivered within September 2007.

### 6.2 New Calorimeter Readout

At the time of submitting our EoI, we were studying the possibility of increasing the readout granularity of the electromagnetic calorimeter (EmC) by replacing the KLOE fine-mesh photomultipliers with multi-anode photomultipliers. It turns out, however, that this solution, although easily available on the market, is inpractical, since these devices do not work inside a magnetic field, and, more importantly, since their usage would require an enormous installation effort.

We have turned our attention to the high-quantum-efficiency (HQE) photomultipliers, recently introduced on the market by Hamamatsu. The advantage of HQE rests in a possible increase in time-resolution (thus longitudinal coordinate resolution) and in a higher detection efficiency for low-energy photons. At present the company has produced the first prototypes of the HQE version of the KLOE fine-mesh tubes. Tests on these prototypes have had encouraging results, therefore we have started a coordinated R&D effort, in collaboration with Hamamatsu, to develop a HQE device fit for the KLOE-2 purposes. If this solution is available, it would have the big advantage of requiring minimal installation work. In the meantime, we are performing Monte Carlo calculations to assess the impact on physics of the use of these devices.

### 6.3 The $\gamma$-$\gamma$ tagger

From the study of the kinematics of the reaction $ee \rightarrow ee\pi\pi$ one sees that most of the scattered electrons are emitted in the forward directions, escaping detection by KLOE. Since the energy of these electrons is less than 510 MeV, they deviate from the equilibrium orbit during the propagation along the machine lattice. Therefore a tagging system should consists of one or more detectors located in well identified regions along the beam line, aimed at determining the energy of the scattered electrons from the measurement of their displacement from the main orbit.

A simple simulation shows that electrons with energy $E \leq 200$ MeV hit the vacuum chamber within a distance of about 80 cm from the IP, just before entering the quadrupole QF1s of the new interaction region. On the other hand, electrons with energy $E > 200$ MeV are focused by this quadrupole and leave the vacuum chamber downstream the bending magnet (the simulation of the trajectories followed by these electrons is still under study).

Therefore the tagging system should consist of two detectors for each beam: i) a low-enegy tagger (LET) located before QF1s (i.e. inside KLOE), and ii) a high-energy tagger (HET) located beyond the bending magnet. Both detectors are of fundamental importance for an accurate measurement of the $\gamma\gamma \rightarrow \pi\pi$ cross section. In particular, the HET is crucial for testing the ChPT predictions, because it covers the $\gamma\gamma$ invariant mass region $W_{\gamma\gamma} \leq 600$ MeV, where the chiral expansion applies.

We propose to use a silicon microstrip detector (with O(100) strips) to measure the displacement of the scattered electron, backed by a set of scintillators for synchronization with the RF signal of the electron beam and fast triggering. A prototype of this detector has been built with the goal of testing its performance during the SIDDHARTA run. It will be installed externally to the beam pipe connecting QD0 to QF1s, at about 20 cm from the exit face of QD0 (LET position). The aim of the test is to understand what is the maximum rate that can be tolerated by the detector. A satisfactory operability in the LET position, with a much higher machine background level than the HET, is in fact a test of feasibility for the entire tagging system.

## 6.4 The new QCAL and photon vetos

There are physics and technical motivations to look for calorimetry upgrades apart from the main EmC. For instance, the new design of the IR substantially modifies the lowest polar angle, $\theta_{max}$, covered by the quadrupoles (with respect to KLOE). This change could have a large impact on acceptance for the analyses based on prompt photons from IP (most of $K^0_S$ and hadronic physics searches). In the present IR scheme, $\theta_{max}$ has been increased from 8° to $\sim 18^\circ$ which practically excludes the possibility to use the existing QCAL calorimeter. In the following, we propose two new detectors to cover this region. Moreover, the idea of improving the efficiency of the most performing $K^0_S$ tagger we have, i.e the $K^0_L$ interacting in the calorimeter ( "$K_L$-crash"), suggests also to look for crack-calorimeters to identify $K^0_L$ punching-through the EmC barrel.

### *6.4.1 Calorimetry at low angles*

There are at least three important physics analyses that can gain from having extended calorimetry below $\theta_{max}$: the BR measurements of $K^0_S \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^0\gamma\gamma$ and the search for $K^0_S \rightarrow 3\pi^0$. In the first two cases, a large improvement on background rejection (almost a factor three ) is expected by building a dedicated photon-veto detector down to 8-10°. As specified above, for the $K^0_S \rightarrow 3\pi^0$, our aim is to achieve the first observation of this decay. If calorimetry at low angles could be provided, the overall acceptance would gain a 50$\%$ factor which, together with a $\times$10 statistics improvement of KLOE-2, will get us really close to the observation limit.

We propose to build a crystal calorimeter in this region, *CCALT*, which should have unprecedented performances on timing. Given the close proximity to the beam pipe and the high rate of machine background events, we estimate that, in order to get a reasonable veto function, the time resolution of this calorimeter has to be similar to the one of the main EmC (300 ps at 20 MeV). We can also obtain good energy resolution for the photons at low $\theta$ by kinematic fitting if the crystal calorimetr can provide the photon position with reasonable accuracy. The best candidate is a detector constituted by small crystals of LYSO ($X_0$=1.2 cm) readout by APD. Existing measurement ( [26]) prove that in this readout configuration, the light yield is of $\sim$ 1500 pe/MeV. At 20 MeV, with a $\tau$ of 40 ns and assuming full shower containment, a time resolution of 230 ps could be achieved. Two small barrels of dodecagonal shape with pointing geometry to the IP could accommodate crystals of $\sim 1.5 \times 1.5 \times 10(12)$ cm$^3$ dimensions. R&D on this detector is required in order to clarify some technical points, to make the final crystal choice and then complete the mechanical drawings.

The idea of completing the original KLOE program entails also a per mil measurement of $K_L^0 \to 2\pi^0$ decay. This suggests to go back to our original design and place a detector veto for $K_L^0$ photons in the inner quadrupole region while keeping it below the $\theta_{max}$ angle. This corresponds to have a dodecagonal (or hexagonal) barrel of 1 m length along the z-axis of 5-7 cm thickness, starting from the end of the first inner quadrupole down to the EndCap region. We propose to build a tile-calorimeter, *QCALT*, with square tiles of BC-408 interleaved by lead layers for an equivalent thickness of $\sim 4.5 - 5$ $X_0$. The tiles should have a lateral size, $\Delta L$, of 5-10 cm which have to be placed along the z-axis to improve the position resolution (from 18 cm of the existing QCAL) to $\Delta L/\sqrt{12}$. This will allow us to extend the search for $K_L^0 \to 2\pi^0$ events also to cases with three photons reconstructed in the EmC and one photon in *QCALT*, thus strongly reducing the correction for acceptance. Each single tile readout can be based on WLS shifting (Kuraray Y11-200) either followed by a splicing to clear fibers and PMs or by coupling scintillating fibers directly to the new technology of SiPM (which are now available on the market by Hamamatsu MPPC). R&D and simulation needed to make the final lead and scintillator thickness choice and decide between the two different readout options.

### *6.4.2 Detectors for Kaon punch-through*

The $K_L^0$-crash tagger is based on the identification of $K_L^0$ interaction in the barrel calorimeter by requiring cuts on energy and on the kaon velocity in the $\phi$ center of mass-frame, $\beta^*$, determined by the time of flight measured on the calorimeter. This tag is $\sim$ 30% efficient while 50% of the $K_L^0$ reach the barrel. Our simulation shows that $\sim$ 15% of the kaons do not interact in the EmC and pass through and interact in the cryostat or in the iron yoke. The KLOE mechanical drawing show that some free-space (5-6 cm) exists between the supporting beams of the barrel modules, the cryostat and the modules themselves. Studies are in progress to see if it is possible to insert some detector in the cracks (lead/scifi or lead/scintillating oil), with very rough reconstruction capability, which would be able to fit in the residual space and improve our tag efficiency. We plan to insert two/three different small size prototypes in the barrel feet to measure their tag efficiency during the *phase 0* of the experiment.

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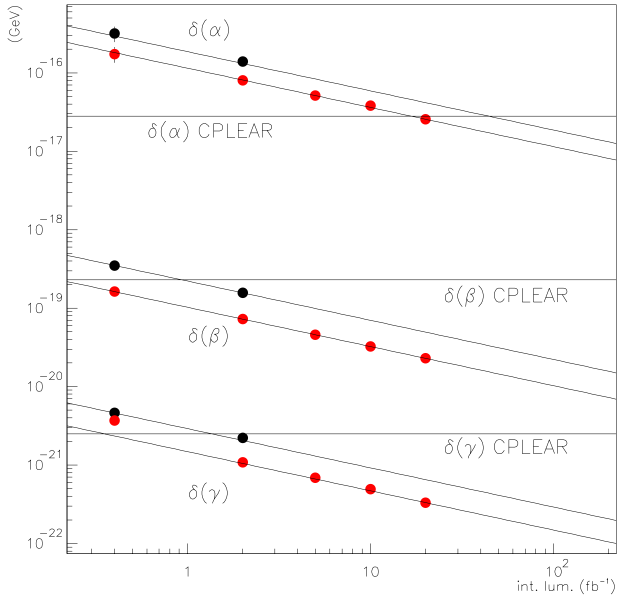

Figure 1: Limits on the CPT violating parameters $\alpha$, $\beta$, and $\gamma$ obtainable by KLOE-2 as a function of the integrated luminosity. Results are presented for a detector both with and without the insertion of an inner tracker with vertex resolution of 0.25 $\tau_S$ (to be compared with the present KLOE vertex resolution, 0.9 $\tau_S$). In the figure also are given results from CPLEAR.

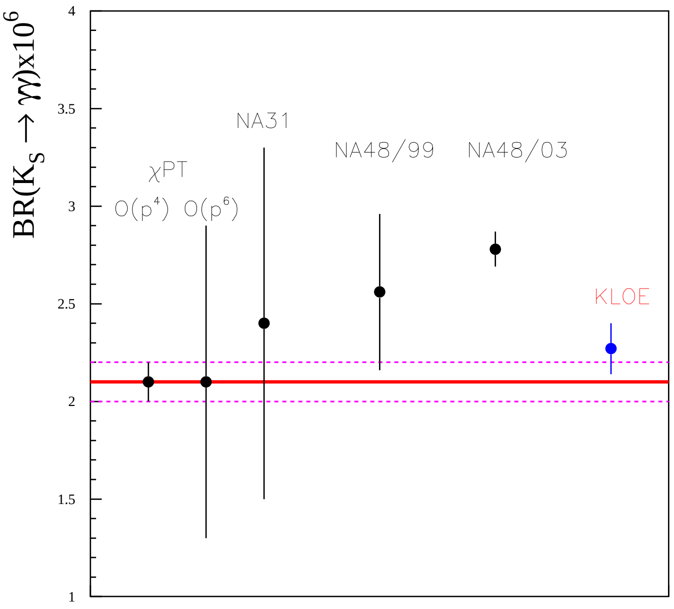

Figure 2: Experimental results from KLOE and NA48 for the decay $K_S^0 \to \gamma\gamma$. The two measurements are in disagreement by more than 3 sigmas. KLOE is in agreement with $O(p^4)$ ChPT calculations, while NA48 suggests a relevant contribution from $O(p^6)$ terms

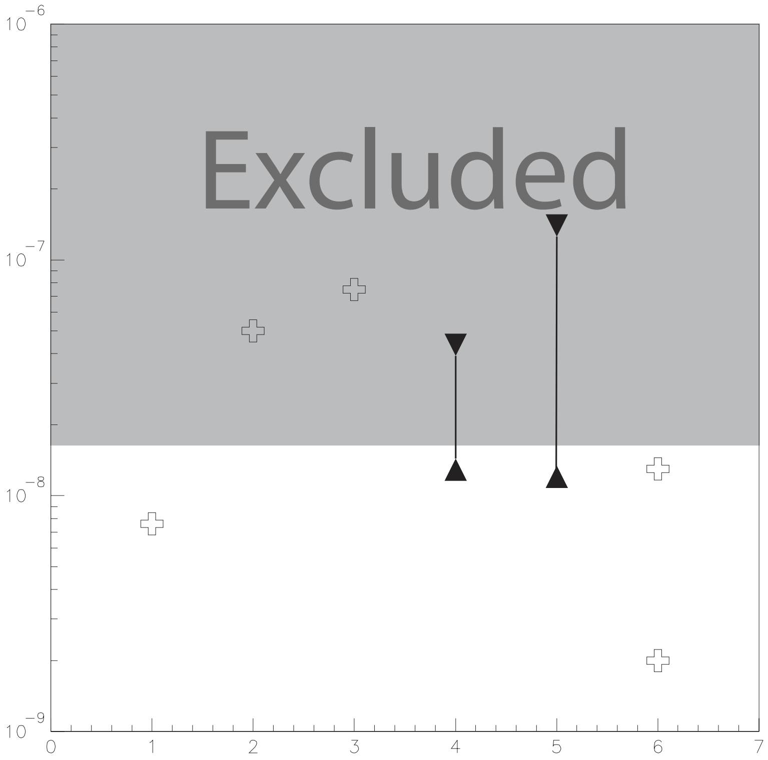

Figure 3: Comparision beetween several theoretical predictions for the branching ratio of the decay $\phi \rightarrow K\overline{K}\gamma$ and the KLOE measurement. See reference [22] for details.