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Physics with the KLOE2 experiment at DAΦNE

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Abstract

We report on the most debated issues which experimentation at the Φ factory can really shed light on with a short-term program of measurements. Recent, very promising improvements in the lattice-QCD calculations call for new precision measurements in the KAON sector to obtain more stringent results on CKM Unitarity and Lepton Flavour Universality. Neutral Kaon Interferometry can probe Discrete Simmetries, but also Quantum Mechanics at the Plank scale. Current limits obtained by KLOE can be overcome by both, the increase in statistics, and the upgrade of the tracking system with an inner GEM chamber for improving vertex resolution near the beam interaction region. One possible solution to the Dark Mass problem, allowing also to interpret the positron excess measured by the satellite payload experiment PAMELA, points to a dark sector that can really be constrained by the experiments at the KAON and B-Factories. Eventually, limiting the presentation to Kaon physics, low energy QCD phenomenology can receive an important contribution from the measurements of Kaon radiative and non-leptonic decays.

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1. Introduction

The DAΦNE facility in frascati has been operating since 1999. Its luminosity has been improving since then, reaching a peak value of 1.6 10^{32} cm^{-2} s^{-1} during 2006. Recently [1] new studies to further improve the DAΦNE luminosity have been performed and showed to be successful. Two phases (STEP0 and STEP1) have been foreseen for the upgrade of the machine and the detector. During STEP0 we'll just benefit of the new machine and much time will be devoted to machine parameter optimization study, on the second phase (STEP1) we'll insert a new detector, the inner tracker, in KLOE. In this paper I'll summarize the relevant upgrades both the machine and the detector are undergoing and their impact on the most relevant physics items KLOE2 can address.

2. Machine Upgrade

In high luminosity colliders with standard collision schemes the key requirements to increase the luminosity are: the very small beta function β_y at the interaction point (IP); the high beam intensity I, the small vertical emittance ε_y. Moreover to minimize beam-beam effects a large horizontal beam size σ_x and a small horizontal emittance ε_x are necessary. It turns out to be very difficult to shorten the bunch in a high current ring without exciting instabilities. The beam current increase may induce high beam power losses, beam instabilities and a remarkable enhancement of the wall-plug power. The machine upgrade proposed for the DAΦNE facility in frascati implements the crab waist (CW) [2] scheme. This scheme proved to work [1] with a moderate beam current and without bunch length reduction. The upgrade of the Φ factory DAΦNE is aimed at increasing the collider luminosity toward to 10^{33} cm^{-2} s^{-1} to be compared with 1.6 10^{32} cm^{-2} s^{-1} obtained during the last DAΦNE run. At the moment we have already obtained a peak luminosity in excess of 4.5 10^{32} cm^{-2} s^{-1} .

The beam parameters used for the simulations are summarized in Table [1]. For comparison, the parameters used during the last DAΦNE run with the FINUDA detector (2006-2007) are also shown.

	DAΦNE FINUDA	DAΦNE UPGRADE
$\theta_{cross}/2$ (mrad)	12.5	25
ε_x (mm mrad)	0.34	0.2
β_x^* (cm)	170	20
σ_x^* (mm)	0.76	0.2
$\Phi_{Phwinsky}$	0.36	2.5
β_y^* (cm)	1.70	0.65
σ_y^* (μm)	5.4	2.6
Coupling %	0.5	0.5
I_{bunch} (mA)	13	13
N_{bunch}	110	110
σ_z^* (mm)	22	20
L(10^{32} cm^{-2} s^{-1})	1.6	10

Table 1

Using the parameters in table 1 and taking into account the finite crossing angle and the hourglass effect a luminosity in excess of 10^{33} cm^{-2} s^{-1} has been estimated. The effect of the CW is also to increase the stability region in the tune shift plane. The "Geographic map" in figure 1 shows the luminosity as a function of the scan. Brighter colors correspond to higher luminosity region. Comparing the two plots we can see that the good luminosity region is much wider thus the optics is much more stable when CW sextupoles are switched on.

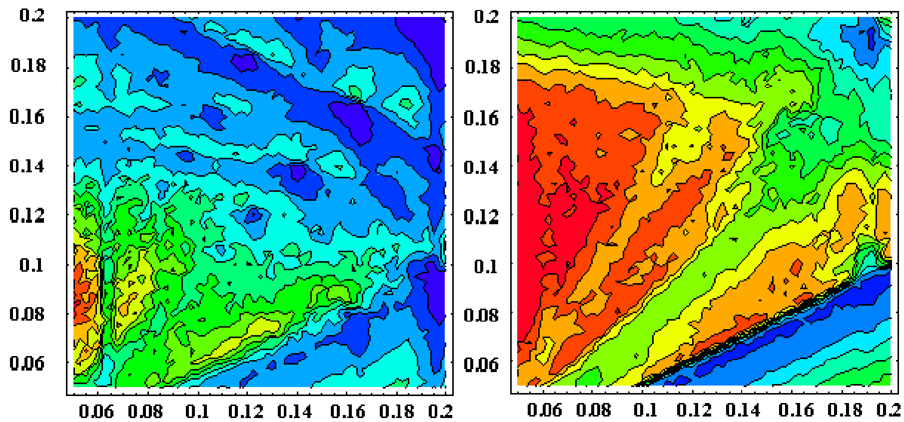

Figure 1: left side: tune shift parameter plane with sextupoles off, right side: tune shift parameter plane with sextupoles on.

3. Detector Upgrade

The detector upgrade has been discussed in detail in reference [3]. I'll only mention here the most relevant features of the Inner Tracker. This detector will consist of 5 independent tracking layers. The spatial resolution will be better than 200 μm on the rϕ plane and better than 500 μm on the z plane. Its active length is 70 cm in z and its radial extension will be between 15 and 25 cm in order to be inserted in the KLOE Drift Chamber. Cylindrical GEM technology has been used to build it. It's total radiation length is 1.8% X_0. Beside the IT, the calorimeter system will be upgraded also well. Two taggers will be inserted in order to study γγ physics. This upgrade will also allow us to improve our capability to study reaction with dark matter candidates in the final state.

4. Future perspectives on kaon physics

The kaon semileptonic decay rate is given by:
$\Gamma(K_{l3}) = (C^2_K G^2_F M^5_K)/192\pi^3(S_{EW} |V_{us}|^2|f_+(0)|^2 I_{K,l}(\lambda)(1+2\Delta_K^{SU(2)} +2\Delta_{K,l}^{EM}))$
Where $K=K^0, K^+, K^-$, l= e, μ and C_K is a Clebsh-Gordan coefficient, equal to ½ and 1 for K^+, K^-, and K^0 respectively. The decay width $\Gamma(K_{l3})$ is experimentally determined by measuring the kaon lifetime and the semileptonic BRs totally inclusive of radiation. The theoretical inputs are: the universal short-distance electroweak correction S_{EW} =1.0232, the SU(2)-breaking $\Delta_K^{SU(2)}$ the long-distance electromagnetic corrections $\Delta_{K,j}^{EM}$ which depends on the kaon charge and on the lepton flavor, and the form factor $f_+(0)$ which parametrizes the hadronic K -> π transitions, evaluated at zero momentum transfer for neutral kaon. Using KLOE present data set, together with the STEP0 statistics, we can improve the accuracy on the measurement of K_L, K^+ , K^- lifetimes and of K_{Se3} branching ratio, with respect to present world average [4]. The present 0.23% fractional uncertainty on $V_{us}f_+(0)$ will reduce to 0.14%, The expected accuracy on V_{us} $f_+(0)$ is listed in Table 2 , for each decay mode and with individual contribution to the total

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uncertainty from branching ratio, lifetime, SU(2)-breaking and long distance EM corrections and phase space integral measurements. Statistical uncertainties on the measurement of BRs and lifetimes have been obtained scaling for the integrated luminosity, adding the 5 fb^{-1} from STEP0 to the present KLOE data.

Mode	$V_{us}f_+(0)$ % error	B	τ	δ	$I_{K,l}$
K_{Le3}	0.21	0.09	0.13	0.11	0.09
$K_{L\mu3}$	0.25	0.10	0.13	0.11	0.15
K_{Se3}	0.33	0.30	0.03	0.11	0.09
(K^+, K^-)	0.37	0.25	0.05	0.25	0.09
(K^+, K^-)	0.40	0.27	0.05	0.25	0.15

Table 2: Future perspectives on $V_{us}f_+(0)$ extracted from K_{l3} decay rates.

A conservative estimate of the systematic contribution to the uncertainties has been done, based on KLOE published analysis, therefore with room for improvement. The measurement of K_{l3} decay rates and in particular of K_{Se3} will certainly benefit from the insertion of the Inner Tracker detector; a more detailed discussion on perspectives on physics related to K_{Se3} decays can be found in [4]. Within few year the accuracy on $f_+(0)$ will reach 0.1% thus allowing us to measure V_{us} with a 0.17% error. The accuracy on the unitarity relation of the first row could reach the level of few 10^{-4} thus allowing to further investigate supersymmetric models with gauge universality breaking.

5. Future perspectives on Interferometry

The decay mode $\phi \to K_S\ K_L \to \pi^+\pi^-\ \pi^+\pi^-$ is very rich in physics. In general all decoherence effects show a deviation from the quantum mechanical prediction [5]. Therefore the reconstruction of events in the region Δt close to the event origin with vertices near the IP, is crucial for precise determination of the parameters related to CPT violation and decoherence. The vertex resolution affects the $I(\pi^+\pi^-\ \pi^+\pi^-,|\Delta t|)$ distribution precisely in that region, as shown in figure 2. The improved vertex resolution reduces the statistical sensitivity of the fit to the parameters and introduces a source of systematic uncertainties. The consequences of the introduction of the inner tracker turn out to be relevant since as a consequence of the improved vertex resolution and a factor 2 or better can be gained on the accuracy of the relevant CPT, QM and Lorentz invariance violating parameters. A definition of these parameters can be found in [6]. Table 3 shows KLOE2 statistical sensitivities to the main parameters that can be extracted from the $I(\pi^+\pi^-\ \pi^+\pi^-,|\Delta t|)$ distribution compared with the best published results.

6. Dark Matter searches

In recent years, several astrophysical observations have failed to find easy interpretations in terms of standard astrophysical and/or particle physics sources.
A non exahustive lists of these observations includes the 511 keV photon signal from the galactic center observed by the INTEGRAL satellite [7], the excess in the cosimic ray positrons reported by PAMELA [8], the total electron and positron flux measured by ATIC [9] and the annual modulation of the DAMA/LIBRA signal [10]. These observations can all be interpreted in terms of the existence of WIMP Dark Matter (DM) candidates belonging to a secluded gauge sector, under which the Standard Model (SM) particles are uncharged, but can still weakly

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couple through a kinetic mixing mechanism with typical mixing parameters k naturally of the order 10^{-2}, 10^{-3}. More interestingly, from the point of view of the present note, the typical mass scale of the vector bosons related to the secluded symmetry is of order 1 GeV within the KLOE

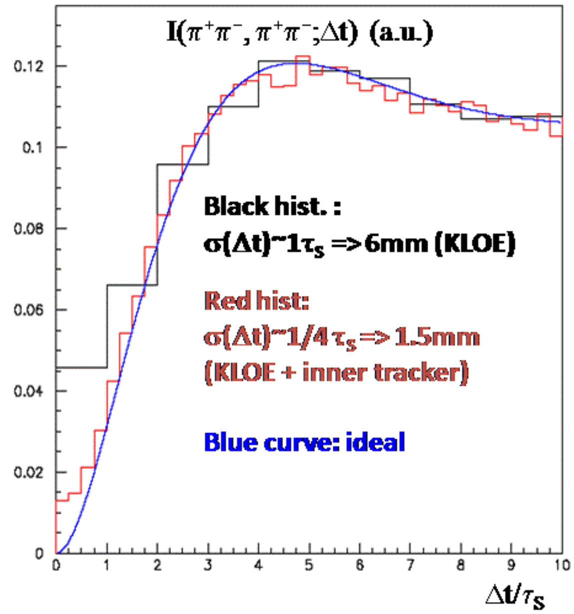

Figure 2: The I($\pi^+\pi^-$ $\pi^+\pi^-$,|Δt|) distribution as a function of |Δt| (in τ_s units) with the present KLOE resolution $\sigma_{|\Delta t|}=\tau_s$ black curve, $\sigma_{|\Delta t|}=\tau_s/4$ red curve. The ideal case is blue.

Mode	Test of	Param	Present value	KLOE2 50 fb^{-1}
$\pi^+\pi^-$ $\pi^+\pi^-$	QM	ζ_{00}	$(1.0 \pm 2.1)\text{x}10^{-6}$	$\pm 0.1\text{x}10^{-6}$
$\pi^+\pi^-$ $\pi^+\pi^-$	QM	ζ_{sl}	$(1.8 \pm 4.1)\text{x}10^{-2}$	$\pm 0.2\text{x}10^{-2}$
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT&QM	α	$(-0.5 \pm 2.8)\text{x}10^{-17}$ GeV	$\pm 2\text{x}10^{-17}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT&QM	β	$(2.5 \pm 2.3)\text{x}10^{-19}$ GeV	$\pm 0.1\text{x}10^{-19}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT&QM	γ	$(1.1 \pm 2.5)\text{x}10^{-21}$ GeV	$\pm 0.2\text{x}10^{-19}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT&EPR	Re(ω)	$(1.1 \pm 7.0)\text{x}10^{-4}$	$\pm 2\text{x}10^{-5}$
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT&EPR	Im(ω)	$(3.4 \pm 4.9)\text{x}10^{-4}$	$\pm 2\text{x}10^{-5}$
$K_{S,L}$–> π eν	CPT&Lorentz	Δa_0	$(0.4 \pm 1.8)\text{x}10^{-17}$ GeV	$\pm 2\text{x}10^{-18}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT&Lorentz	Δa_z	$(2.4 \pm 9.7)\text{x}10^{-18}$ GeV	$\pm 7\text{x}10^{-19}$ GeV

Table 3: KLOE2 most relevant impact on the measurement accuracy on the CPT, QM, Lorentz and EPR parameters.

and KLOE2 physics reach potential. One of the most interesting physics process to be studied is $e^+ e^-$ -> Uγ. Its expected cross section can be as high as 0.1 pb at DAΦNE energy [11]. The on-shell boson can decay into a lepton pair, giving rise to a $l^+ l^- \gamma$ signal. The most relevant physics background comes from the analogous QED radiative process, which has a much higher cross section but can be rejected by cutting on the invariant mass of the lepton pair, as already discussed in [12]. The insertion of the IT can be rather beneficial in this case, since it would help in a better definition of the pair production vertex. A quantitative statement on this issue, however, needs the use of a detailed Monte Carlo simulation, which is at present unavailable. For the muon channel, the above mentioned background is not present. One has to take into account however, the physical process $e^+ e^-$ -> $\pi\pi\gamma$, that is relevant, since π μ separation in highly untrivial at DAΦNE energies. The proposed modification for the second phase of

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KLOE2 should be beneficial, since they increase acceptance for both charged tracks, thanks to the IT, and for photons, thanks to the CCALT. We can conclude that the $l^+ l^- \gamma$ at KLOE2 can be exploited to explore the region m_U > 400-500 MeV. A final note has to be made on the possibility that the U boson decays into two neutral long lived (or stable) particles, either DM WIMPs or neutrinos (as discussed for instance in [13]). In this case the signal would be a single photon plus missing energy. This signal fails to satisfy the KLOE trigger conditions, so it cannot be in the present KLOE data set. Moreover, even assuming the implementation of a dedicated trigger in the future, it would be affected by copious physical as well as machine backgrounds, that produce a single photon signal in the calorimeter at a much higher rate. Here, a key requirement is a very high energy resolution which would help isolating the signal peak over a broad background. Unfortunately the KLOE calorimeter is not conceived for such an high resolution, so that the observation of this signature at KLOE is essentially hopeless.

7. Conclusions

The KLOE2 experiment can address the selected physics items and set stringent limits on new particles through virtual effects or eventually discover them. Even violation effects of discrete symmetries can be excluded or discovered. Moreover KLOE2 can really shed some light on dark matter candidates, this is a relevant physics item it was not originally designed for.

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