KLOE-2 Collaboration - LNF Group

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1 Introduction

Fundamental symmetry tests and physics beyond the Standard Model, including kaon interferometry and searches for new exotic particles that could constitute the dark matter, together with K_S and η meson rare decays are the focus of the KLOE-2 collaboration, exploiting the uniqueness of the largest sample ever collected at the $\phi(1020)$ meson peak at e^+e^- colliders, corresponding to about 2.4×10^{10} ϕ-meson produced.

Continuing the long-standing tradition of flavour physics precision measurements and fundamental symmetries testing in the kaon sector, KLOE-2 Collaboration published in 2023 two papers: *Measurement of the $K_S e3$ branching fraction with the KLOE experiment* [1] and the first *Direct tests of T, CP, CPT symmetries in transitions of neutral K mesons with the KLOE experiment* [2]. The new measurement of the K_Se3 branching ratio, combined with our previous measurement [3], allows a 0.8% precision to be reached, improving by almost a factor of two, together with a sizable reduction of the uncertainty on the corresponding new derivation of $f_+(0)|V_{us}|$ from 0.6% to 0.4%.

Latest physics results achieved in 2023 are: i) the final results on the direct test of T and CPT symmetries in neutral kaon transitions and ii) preliminary results on the "from future to past" effect in $\phi \to K_S K_L \to \pi^+\pi^-, \pi^+\pi^-$. These measurements together with preliminary results from other ongoing analysis, both with KLOE and KLOE-2 samples, have been presented at several international conferences and workshops including EPS-HEP 2023 [4, 5, 6] and CKM 2023.

Finally, a new group from Liverpool joined the KLOE-2 collaboration to measure the hadronic cross-section with Initial State Radiation (ISR) method, thanks to the renewed interest on this measurement after the first results from g-2 at FNAL and the CMD-3 hadronic cross-section measurement with the energy scan technique.

2 Data Preservation

According to the KLOE-2 long-term Data Preservation plan, along with data reconstruction and simulation, a ROOT output of the DBV-40 reconstructed data is being produced, with a negligible CPU time usage. The output production for KLOE-2 data was completed with neutral kaons, charged kaons, radiative decays and $\rho\pi$ streams produced with a compression factor of about 8 depending on run conditions. The present effort is focused on the production of the ROOT output for KLOE-2 MC, already tested with physics streams, and then both KLOE data and MC. To facilitate analysis, the ROOT files will be kept on disk. Data reprocessing dedicated to the new hadronic cross-section measurement is being planned, to modify the criteria used for the signal sample selection.

3 Data Distribution Upgraded with AI Revolutionary and Transparent Support

During the last year, besides the usual management activities, KLOE-2 CED carried on some important planning operations. Several cornerstone devices were upgraded and renewed, increasing speed and bandwidth aimed to make more and more analyses simultaneously. The Fibre Channel is now our first protocol to deploy data around the cluster, overcoming every issue related to Ethernet protocols together with the traditional client-server architecture, for a better and more efficient peer-to-peer distribution.

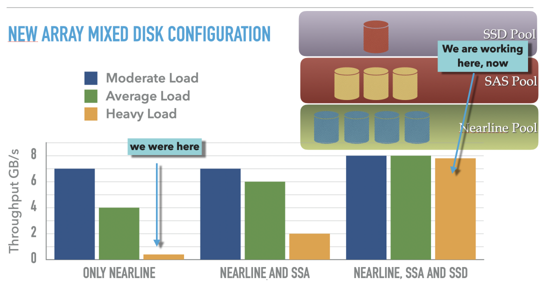

Figure 1: Disk Arrays Speed and Bandwidth.

The gained bandwidth is a top score for our computer cluster and its continuously improving every time we increase the number of parallel components in the fiber channel network. Every computer has reached the full bandwidth available on its devices or on its cards. The IO state close to zero is our best result: programs never wait for data from disk devices, these are always available for the software code and the computing times (CPU Time) is the only waiting time of the programs.

These results were achieved with the steps hereafter described.

i) Introduction of a new high-capacity SSD disk on top of the tiering level besides the memory buffer of the top in/out devices, the only visible by the running programs and prone to answer back in a few microseconds.

ii) A redundant fiber channel network with an auto-balanced throughput carries on data in and out of the disk array systems, aggregating multichannel fiber networks.

iii) The AI manages the data moving from a very fast RAM memory buffer to a fast SSD disk to the last level built with slow but capacious technologies disk array like SAS, SATA, and Ultra SATA disk. There are no rules pre-inserted on the tiering model but the AI adapts the rules to our kinds of jobs every second we are working on. This allows more than 800 reconstruction jobs to be afforded with more the 120000 files opened simultaneously. 24/7 there is an AI working to organize and optimize the access to files belonging to the array. The AI is moving files in and out from the three caching levels with the purpose of minimizing the access time and, as shown in Fig.2 panels, the results are very good before the SSD upgrade and outstanding after the upgrade.

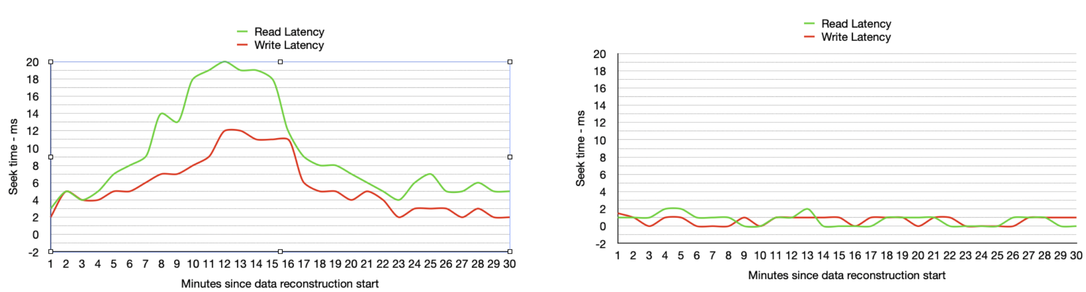

Figure 2: Disk Arrays read/write latency before (left) and after (right) the update.

iv) The algorithm of the AI, designed to satisfy the file-hungry jobs, is well suited to our typical job request and is becoming every day better in its tasks. Every time the AI model controlling the file distribution is becoming more expert in our file usage and the files necessary for jobs running into the HPC cluster are managing to increase the speed and lower the access time. Presently, every job running on the cluster works without interference from other jobs, as if it were alone in the cluster.

The job submission system, based on a Condor-derived protocol and the GPFS file system, managed more than 200.000 jobs during the last year without missing even a single job. It dispatched and managed efficiently the load into the KLOE-2 computing cluster, working as a High-Performance Computing in a parallel way with a high level of latency. This cluster with the new job submission system is the keystone of the KLOE-2 tasks, fitting the jobs to the cluster resources without over-heading even a single processor, so to keep the efficiency at the top level.

In conclusion, we managed the tasks required from KLOE-2 experiment reconstruction and analysis in a powerful environment used to face every request needed. Continuous studies for a new computational model have been developed with the not used power or during the idle time of the main tasks, because every simulation runs in a parallel environment extruded from the main one, partitioning resources and using them to bump not into one another.

4 Physics Analysis Updates

In the following sections latest updates obtained analysing the unique data sample collected by KLOE and KLOE-2 experiments will be discussed, in both kaon and hadron sectors.

4.1 "From future to past effect" in $\phi \to K_S K_L \to \pi^+\pi^-, \pi^+\pi^-$

Novel quantum phenomena have been recently discussed [7] in association to a peculiar time correlation between entangled neutral kaons produced at a ϕ-factory: the past state of the first decayed kaon, when it was still entangled before its decay, is post-tagged by the result and the time of the future observation on the other kaon decay. This surprising "from future to past" effect is fully observable and leads to the unique experimental tag of the K_S state, an unsolved problem since the discovery of CP violation. A data sample of about 1.7 fb^{-1} integrated luminosity has been analysed, to study the t_1 distribution of the first decaying kaon in the $\phi \to K_S K_L \to \pi^+\pi^-, \pi^+\pi^-$ process [5] in two different cases: (i) the decoherence regime with $t_2 > 30\ \tau_S$ and the KS-tag condition satisfied, (ii) the interference regime with $2.5 < t_2 < 3\ \tau_S$.

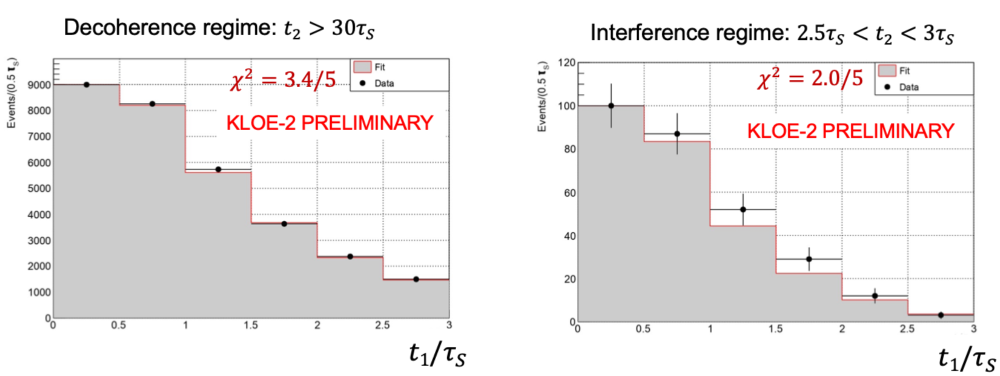

Figure 3: The measured t_1 distribution for $\phi \to K_S K_L \to \pi^+\pi^-, \pi^+\pi^-$ events (black dots) and the fit results (histogram) with the prediction of quantum mechanics.

The preliminary results in Fig. 3 show a first experimental evidence of the effect "from future to past" obtained with $\phi \to K_S K_L \to \pi^+\pi^-, \pi^+\pi^-$ events from KLOE data. The measured t_1 distribution for $\phi \to K_S K_L \to \pi^+\pi^-, \pi^+\pi^-$ events (black dots), in the case of the decoherence regime with $t_2 > 30\ \tau_S$ (left), and the interference regime with $2.5 < t_2 < 3\ \tau_S$ (right). The histogram shows the result of the fit with the prediction of quantum mechanics, taking into account the experimental resolution effects on t_1 and t_2 from Monte Carlo simulation.

4.2 π^0 production from $\gamma\gamma$ scattering

During 2023 a beam test of the HET tagger stations has been conducted at the Frascati Beam Test Facility (BTF), to finalize the evaluation of tagger acceptances and the study of systematics on the the measurement of the cross section of $e^+e^- \to e^+e^-\gamma^{(*)}\gamma^{(*)} \to e^+e^-\pi^0$ with the KLOE-2 data sample. The aim is to control efficiency and relative positions of the scintillators, obtained by the exposure of the tagging channels to single-particle beams of 450 MeV electrons provided by the BTF with a spatial resolution of few hundrends microns. HET position was varied during the test both in x and y directions to obtain the response of all scintillators in different detector regions. From these measurements we have obtained the validation of the simulation of Bhabha scattering events at very low angle.

4.3 New measurement of the hadronic cross-section with the radiative return method

In recent years, there is lot of effort in the particle physics community to understand the long-standing discrepancy between the experimental and theoretical values of the muon anomalous magnetic moment, a_μ. The recent measurement of Muon (g-2) Collaboration [8] improves by more than a factor of two the value published in 2021, confirming the previous result and increasing the discrepancy from the Standard Model evaluation based on e^+e^- data [9] to more than 5 σ's. On the other hand, recent lattice QCD calculations [10] give results which are in better agreement with the experimental measurement. Moreover, the tension in the results on the hadronic cross section from e^+e^- collider experiments is motivating new measurements, as the recent CMD-3 result. [11]

The KLOE-2 Collaboration is aiming to perform a new measurement of the $e^+e^- \to \pi^+\pi^-$ cross section with the radiative return method, exploiting a larger dataset available, with the goal of obtaining a 0.4% total error on a_μ. Differently form past hadronic cross section measurements, we are developing a blind analysis procedure to avoid the possibility of a bias in the result.

In order to reduce systematic errors, the analysis is performed normalizing the $e^+e^- \to \pi^+\pi^-\gamma$ events with the $\mu^+\mu^-\gamma$ final state. The event selection requires two tracks at large angle ($50^\circ < \theta_{\pi,\mu} < 130^\circ$) and an un-tagged small angle photon ($\theta_{miss} < 15^\circ$ or $\theta_{miss} > 165^\circ$).

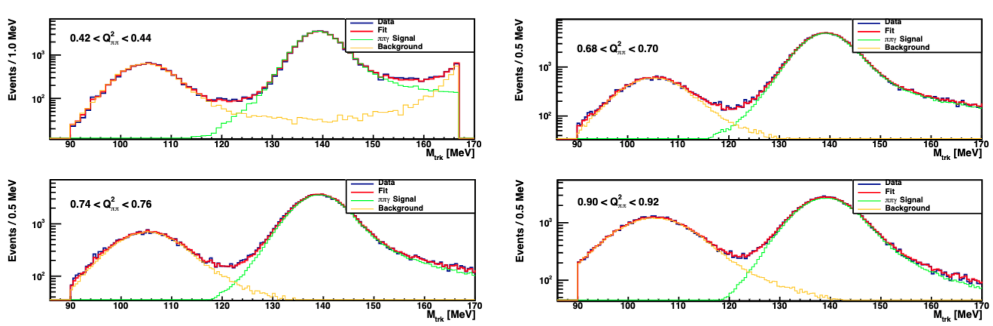

Figure 4: Fit to the track mass variable, M_{trk}, for different $Q^2_{\pi\pi}$ bins. Data (blue) are fit with Monte Carlo signal (green) and background (yellow) contributions. The fit result is reported in red.

The signal and background contributions are extracted fitting for each 0.02 GeV^2 bin of $Q^2_{\pi\pi}$ the trackmass variable, M_{trk}, derived from the 4-momentum conservation under the hypothesis of events with two equal-mass charged tracks and a photon. Example of fits to the M_{trk} for different $Q^2_{\pi\pi}$ values are reported in Fig. 4.

Work is in progress to refine selection cuts, define the blinding strategy, and improve the unfolding procedure.

5 List of Conference Talks in Year 2023

- C. Bloise, "Direct tests of T, CP, CPT symmetries in transitions of neutral K mesons with the KLOE experiment", EPS-HEP 2023, Hamburg, Germany
- A. Di Domenico, "Observation of the post-tagging effect for entangled K mesons at KLOE", EPS-HEP 2023, Hamburg, Germany
- P. Gauzzi, "Hadron physics results at KLOE-2", EPS-HEP 2023, Hamburg, Germany
- A. Passeri, "The new $K_S \to \pi e \nu$ branching fraction measurement at KLOE", 12^{th} International Workshop on CKM Unitarity triangle, Santiago de Compostela 2023
- G. Mandaglio, "Latest Hadron Physics results at KLOE-2", 20^{th} International Conference on Hadron Spectroscopy and Structure (HADRON 2023), Genova (IT), 5-9 June 2023
- S. Giovannella, "Light Meson Decays at KLOE/KLOE-2", Precision Tests of Fundamental Physics with Light Mesons, ECT*, Trento (IT), 12-16 June 2023
- E. Perez Del Rio, "Hadron Physics results at KLOE-2", MESON2023, Krakow (PL), 22-27 June 2023
- G. Mandaglio, "Hadron physics results at KLOE-2", 6^{th} Plenary Workshop of the Muon g-2 Theory Initiative, Zurich (CH), 4-8 September 2023
- P. Gauzzi, "Latest results from KLOE/KLOE-2", 16^{th} International Conference on Meson-Nucleon Physics and the Structure of the Nucleon (MENU 2023), Mainz (DE), 16-20 October 2023

6 List of Publications in Year 2023

- Babusci D *et al* JHEP02 (2023) 098 and https://arxiv.org/abs/2208.04872v4
- Babusci D *et al* Phys. Lett. B 138164 (2023) and https://arxiv.org/abs/2211.12377v3
- C. Bloise for the KLOE-2 Collaboration, "Direct tests of T, CP, CPT symmetries in transitions of neutral K mesons with the KLOE experiment", PoS(EPS-HEP2023)372
- A. Di Domenico for the KLOE-2 Collaboration, "Observation of the post-tagging effect for entangled K mesons at KLOE", PoS(EPS-HEP2023)371
- P. Gauzzi P for the KLOE-2 Collaboration, "Hadron physics results at KLOE-2", PoS(EPS-HEP2023)449

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1. Babusci D *et al* JHEP02 (2023) 098 and https://arxiv.org/abs/2208.04872v4
2. Babusci D *et al* Phys. Lett. B **845** 138164 (2023) and https://arxiv.org/abs/2211.12377v3
3. Ambrosino F *et al* Phys. Lett. B **636** 173 (2006)
4. Bloise C for KLOE-2 Collaboration, PoS(EPS-HEP2023)372
5. Di Domenico A for KLOE-2 Collaboration, PoS(EPS-HEP2023)371
6. Gauzzi P for KLOE-2 Collaboration, PoS(EPS-HEP2023)246
7. J. Bernabeu, A. Di Domenico, Can future observation of the living partner post-tag the past decayed state in entangled neutral K mesons?, Phys. Rev. D 105 (11) (2022) 116004. arXiv: 1912.04798, doi:10.1103/PhysRevD.105.116004.
8. D. P. Aguillard *et al*, "Measurement of the Positive Muon Anomalous Magnetic Moment to 0.20 ppm", Phys. Rev. Lett. 131, 161802 (2023)
9. T. Aoyama *et al*, "The anomalous magnetic moment of the muon in the Standard Model", Phys. Rep. 887, 1 (2020)
10. S. Borsanyi *et al*, "Strong isospin breaking correction to the muon anomalous magnetic moment from lattice QCD at the physical point", Phys. Rev. Lett. 121 022002 (2018)
11. F. V. Ignatov *et al*, "Measurement of the $e^+e^- \to \pi^+\pi^-$ cross section from threshold to 1.2 GeV with the CMD-3 detector", accepted by Phys. Rev. D, arXiv:2302.08834