Flavour physics and CP violation at KLOE-2

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Abstract.
The KLOE-2 experiment at the upgraded $e^+e^-$ DAΦNE collider of the INFN Laboratori Nazionali di Frascati completed its data taking campaign at the end of March 2018, collecting 5.5 fb$^{-1}$ at the center of mass energy corresponding to the mass of the φ-meson. Together with the data set of its predecessor KLOE, the acquired data sample of 8 fb$^{-1}$ corresponds to $2.4 \times 10^{10}$ φ-meson produced: the largest sample ever collected at the φ(1020) at $e^+e^-$ colliders.

KLOE-2 Collaboration activities are now focused on data reconstruction and analysis, continuing the KLOE long-standing tradition of flavour physics precision measurements in the kaon sector, to probe CKM unitarity and search for dark force mediator. Latest results on $K_S$ rare decays will be presented and discussed in the framework of Flavour Physics and CP Violation tests, focusing on the measurement of $K_S$ semileptonic branching ratios, using 1.7 fb$^{-1}$ KLOE data, and the search for the pure CP-violating $K_S \to 3\pi^0$ decay.

1. Introduction
The KLOE experiment at the Frascati National Laboratory was placed at the DAΦNE φ-factory, an electron–positron collider running at the centre-of-mass energy of 1.02 GeV. The φ mesons are produced with a small transverse momentum of 13 MeV and $K_L$–$K_S$ pairs are produced almost back-to-back with a cross section×branching fraction of about 1 µb. The KLOE experiment took data from 2001 to 2006, collecting 2.5 fb$^{-1}$; several measurements have been performed on this data sample, mainly on precision Kaon physics and hadron physics [1]. The KLOE-2 experiment started in 2014 after detector upgrade [2], ending in March 2018, after collecting 5.5 fb$^{-1}$. The total KLOE and KLOE-2 data sample consist of $\sim 8$ fb$^{-1}$, corresponding to $\sim 2.4 \times 10^{10}$ φ meson decays, and $\sim 8 \times 10^8$ $K_L K_S$ pairs, that is a unique data sample for topology and statistical relevance. On this data sample several physics analyses are performed, mainly concerning Kaon physics and discrete symmetries tests, search of a dark force mediator, and hadronic physics [3].

2. The KLOE detector
The detector consists of a large volume cylindrical drift chamber, surrounded by a lead/scintillating fibers finely-segmented calorimeter. A superconducting coil around the calorimeter provides a 0.52 T axial magnetic field. The beam pipe at the interaction region is spherical in shape with 10 cm radius, made of a 0.5 mm thick beryllium-aluminum alloy. Low-beta quadrupoles are located at ±50 cm from the interaction region. Two small lead/scintillating-tile calorimeters are wrapped around the quadrupoles.

The drift chamber [4], 4 m in diameter and 3.3 m long, has 12582 drift cells arranged in 58 concentric rings with alternated stereo angles and is filled with a low-density gas mixture of
90% helium–10% isobutane. The chamber shell is made of carbon fiber-epoxy composite with an internal wall of 1.1 mm thickness at 25 cm radius. The spatial resolution is $\sigma_{xz} \sim 150 \, \mu m$ and $\sigma_z \sim 2 \, mm$ in the transverse and longitudinal projection, respectively. The momentum resolution for long tracks is $\sigma_{p_T}/p_T \sim 0.4\%$. Vertices are reconstructed with a spatial resolution of $\sim 3 \, mm$.

The calorimeter [5] is divided into a barrel and two endcaps and covers 98% of the solid angle. The readout granularity is $4.4 \times 4.4 \, cm^2$, for a total of 2440 cells arranged in five layers. Each cell is read out at both ends by photomultipliers. The energy deposits are obtained from signal amplitudes while the arrival time and the position along the fibers are obtained from time differences. Cells close in time and space are grouped into energy clusters. The cluster energy $E$ is the sum of the cell energies, the cluster time and position are energy-weighted averages. Differences. Cells close in time and space are grouped into energy clusters. The cluster energy $E$ is the sum of the cell energies, the cluster time and position are energy-weighted averages. Energy and time resolutions are $\sigma_E/E = 0.057/\sqrt{E} \, (GeV)$ and $\sigma_t = 54 \, ps/\sqrt{E} \, (GeV) \oplus 100 \, ps$, respectively. The cluster space resolution is $\sigma_{\parallel} = 1.4 \, cm/\sqrt{E} \, (GeV)$ along the fibers and $\sigma_\perp = 1.3 \, cm$ in the orthogonal direction.

For the KLOE-2 data taking, the detector was upgraded, inserting a vertex detector consisting of four layers of cylindrical triple GEM detector (Inner Tracker), two calorimeters to increase calorimeter hermeticity (QCALT and CCALT), and two $\gamma\gamma$ tagging detectors (HET and LET) [2].

3. The KLOE tagging technique

The $K_S$ ($K_L$) mesons are identified (tagged) with high efficiency and purity by the observation of a $K_L$ ($K_S$) in the opposite hemisphere. Kaons from $\phi$-meson decays are emitted almost back to back, with decay path $\lambda_S = 5.9 \, mm$ and $\lambda_L = 3.4 \, m$, thus about 50% of $K_L$ mesons reach the calorimeter before decaying. The velocity of the $K_L$ in the $\phi$ reference system is $\beta^* = 0.22$. $K_S$ mesons are tagged by $K_L$ interactions in the calorimeter, $K_L$-crash in the following, with a clear signature of a delayed cluster not associated to tracks. Events are selected with the following requirements:

- a cluster with energy $E_{clu} > 100 \, MeV$ not associated to tracks (neutral cluster); the centroid of the neutral cluster defines the $K_L$ direction with a resolution of $\sim 1^\circ$;
- polar angle of the neutral cluster $15^\circ < \theta_{clu} < 175^\circ$ to suppress small-angle beam backgrounds;
- $0.17 < \beta^* < 0.28$ for the velocity in the $\phi$ reference system of the particle originating the neutral cluster; $\beta^*$ is obtained from the velocity in the laboratory system, $\beta = r_{clu}/ct_{clu}$, with $t_{clu}$ being the cluster time and $r_{clu}$ the distance from the nominal interaction point, the $\phi$ momentum and the angle between the $\phi$ momentum and the $K_L$-crash direction;

Assigning the neutral kaon mass, the $K_S$ 4-momentum is defined by the $K_L$-crash direction, the $\phi$ 4-momentum and the angle between the $\phi$ momentum and the $K_L$-crash direction: $P_{K_S} = P_\phi - P_{K_L}$.

4. $K_S \to \pi^0\pi^0\pi^0$

4.1. Motivations

CP violation in three body decays of neutral kaons is characterized in terms of the following amplitude ratios $\eta_{+-0} = A(K_S \to \pi^+\pi^-\pi^0)/A(K_L \to \pi^+\pi^-\pi^0) \equiv \epsilon + \epsilon'_{+-0}$ and $\eta_{000} = A(K_S \to \pi^0\pi^0\pi^0)/A(K_L \to \pi^0\pi^0\pi^0) \equiv \epsilon + \epsilon'_{000}$, where $\epsilon$ is a complex parameter expressing the indirect CP violation, and at the lowest order of the Chiral Perturbation Theory $\epsilon'_{+-0} = \epsilon'_{000} = -2\epsilon'$, where $\epsilon'$ is a complex parameter expressing the direct CP violation [6]. Since the two CP-violating decays $K_S \to \pi^+\pi^-\pi^0$ and $K_S \to \pi^0\pi^0\pi^0$ have not yet been measured, the parameter $\eta_{+-0}$ and $\eta_{000}$ are not well known. In particular $K_S \to \pi^0\pi^0\pi^0$ branching fraction is predicted to be very small in the Standard Model, $\sim 2 \times 10^{-9}$.
4.2. Analysis strategy
The search for the $K_S \to 3\pi^0 \to 6\gamma$ decay is then carried out by the selection of events with six photons whose momenta are reconstructed using time and energy measured by the electromagnetic calorimeter. Background for the searched decay originates mainly from the $K_S \to 2\pi^0$ events with two spurious clusters from fragmentation of the electromagnetic showers (so called splitting) or accidental activity, or from false $K_L$ identification of $\phi \to K_SK_L \to \pi^+\pi^\mp \pi^0 \pi^0$ events. In the latter case charged pions from $K_S$ decays interact in the DA(φ)NE low – beta insertion quadrupoles, ultimately simulating the $K_L$ interaction in the calorimeter ($K_L$-crash), while $K_L$ decays close to the IP producing six photons. To suppress this kind of background, events with charged particles coming from the vicinity of the interaction region are rejected. Moreover, $K_L$-crash selections are tightened to reject fake $K_L$-crash:

- $E_{\text{clu}} > 150$ MeV
- $0.20 < \beta^* < 0.225$

In the next stage of the analysis a kinematic fit with 11 constraints is performed: energy and momentum conservation, the kaon mass and the velocity of the six photons. Cutting on the $\chi^2$ of the fit considerably reduces the background from bad quality reconstructed events with a very good signal efficiency. In order to reject events with split and accidental clusters, the correlation between two $\chi^2$-like discriminating variables $\chi^2_{2\pi}$ and $\chi^2_{3\pi}$ is analyzed. The $\chi^2_{2\pi}$ is calculated by an algorithm selecting four out of six clusters, the best for the kinematic constraints of the two – body decay to test the $K_S \to 2\pi^0 \to 4\gamma$ hypothesis. The pairing of clusters is based on the requirement $m_{\gamma\gamma} = m_{\pi\pi}$, and on the opening angle of the reconstructed pions direction in the $K_S$ frame. Moreover, we check the consistency of the energy and momentum conservation in the $\phi \to K_SK_L$, $K_S \to 2\pi^0$ decay hypothesis. The $\chi^3_{3\pi}$ instead verifies the signal hypothesis by looking at the reconstructed masses of three pions. For every choice of cluster pairs the quadratic sum of the residuals between the nominal $\pi^0$ mass and the invariant masses of three photon pairs is calculated. In order to improve the quality of the photon selection using $\chi^2_{2\pi}$, a cut on the variable $\Delta E = (m_\phi/2 - \Sigma_i E_{\gamma i})/\sigma_E$ is provided, where $\gamma_i$ stands for the $i$-th photon among those chosen by the estimator and $\sigma_E$ is the appropriate resolution. For $K_S \to 2\pi^0$ decays plus two background clusters, $\Delta E \sim 0$ is expected, while for $K_S \to 3\pi^0 \Delta E = m_{\pi^0}/\sigma_E$. In addition a cut on the minimal distance between photon clusters to refine rejection of events with split clusters is also applied.

From 1.7 $fb^{-1}$ of the KLOE data sample, no candidates were found, with zero background events expected from Monte Carlo simulations of a sample two times larger than that of the data. Estimation of systematic uncertainties of background evaluation is being finalized. Normalizing to $K_S \to 2\pi^0$, the upper limit on the $K_S \to 3\pi^0$ branching fraction is $BR(K_S \to 3\pi^0) < 2.6 \times 10^{-8}$ at 90% confidence level [7].

4.2.1. KLOE-2 data sample
The analysis of the first 2 $fb^{-1}$ of KLOE-2 integrated luminosity is ongoing. Selection criteria are hardened to cope with the observed increased machine background with respect to KLOE data. Preliminary results show that this new selection criteria increase machine background rejection by a factor ten, without loss of efficiency. Moreover, a Neural Network analysis approach is under study; first test using the KLOE data shows a factor two better in background rejection with almost the same MC efficiency.

5. $K_S \to \pi \ell \nu$
5.1. Motivations
The branching fraction for semileptonic decays of charged and neutral kaons together with the lifetime measurements are used to determine the $|V_{us}|$ element of the Cabibbo–Kobayashi–Maskawa quark mixing matrix. The relation among the matrix elements of the first row,
\(|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1\), provides the most stringent test of the unitarity of the quark mixing matrix. Different factors contribute to the uncertainty in determining \(|V_{us}|\) from kaon decays [8, 9, 10] and among the six semileptonic decays the contribution of the lifetime uncertainty is smaller for the \(K_S\) meson. Nevertheless, given the lack of pure high-intensity \(K_S\) meson beams compared with \(K^\pm\) and \(K_L\) mesons, the \(K_S \rightarrow \pi e\nu\) decay provides the least precise determination of \(|V_{us}|\), and the branching fraction \(B(K_S \rightarrow \pi \mu \nu)\) has not yet been measured.

5.2. Analysis strategy

The branching fraction for the \(K_S \rightarrow \pi \ell \nu\) decay is evaluated as

\[
B(K_S \rightarrow \pi \ell \nu) = \frac{N_{\pi \ell \nu}}{N_{\pi \pi}} \times \frac{\epsilon_{\pi \pi}}{\epsilon_{\pi \ell \nu}} \times R_{\epsilon} \times B(K_S \rightarrow \pi^+ \pi^-),
\]

(1)

where \(N_{\pi \ell \nu}\) and \(N_{\pi \pi}\) are the numbers of \(K_S \rightarrow \pi \ell \nu\) and \(K_S \rightarrow \pi^+ \pi^-\) events, \(\epsilon_{\pi \ell \nu}\) and \(\epsilon_{\pi \pi}\) are the respective selection efficiencies, and \(R_{\epsilon}\) is the ratio of the efficiencies for the preselections, that can be different for signal and normalization sample.

Initially, \(K_L\)-crash are selected (see Section 3), and \(K_s\) ID candidates are identified, requiring two tracks of opposite curvature forming a vertex in the cylinder \(\rho_{vtx} = \sqrt{x_{vtx}^2 + y_{vtx}^2} < 5\) cm, \(z_{vtx} < 10\) cm.

Then, the selection of signal events is performed in two steps. First a selection based on the event kinematics using only tracking variables, second a selection based on the time-of-flight measured with the calorimeter. The two groups of variables are uncorrelated. To assign a time to the tracks connected to the vertex there is need to associate each track to a cluster.

Five variables with good discriminating power against background are used as input of a Boosted Decision Tree (BDT) classifier.

The distribution of the BDT classifier output is shown in Figure 1 (for \(K_S \rightarrow \pi e\nu\)) and Figure 2 (for \(K_S \rightarrow \pi \mu \nu\)), for data and both simulated signal and background events.

The data distribution is well reproduced by simulation in the region populated by the signal.

![Figure 1. Distribution of the BDT classifier output for the data and MC signal \(K_S \rightarrow \pi e\nu\) events, background events and their sum.](image1)

![Figure 2. Distribution of the BDT classifier output for the data and MC signal \(K_S \rightarrow \pi \mu \nu\) events, background events and their sum.](image2)

To reduce the large background of \(K_S \rightarrow \pi^+ \pi^-\) and \(\phi \rightarrow K^+ K^-\) events, a cut is applied

\[
BDT > 0.150 \quad \text{for} \quad K_S \rightarrow \pi e\nu; \quad BDT > 0.180 \quad \text{for} \quad K_S \rightarrow \pi \mu \nu
\]

(2)

After the BDT analysis, a selection based on time-of-flight measurement is performed to suppress the remaining background. For each track associated to a cluster, the difference between the
time-of-flight measured by the calorimeter and the time-of-flight measured along the particle trajectory
\[ \delta t_i = t_{\text{clu},i} - L_i/c\beta_i \quad i = 1, 2 \]
is computed, where \( t_{\text{clu},i} \) is the time associated to track \( i \), \( L_i \) is the length of the track, and \( \beta_i = p_i/\sqrt{p_i^2 + m_i^2} \) is function of the mass hypothesis for track \( i \). The times \( t_{\text{clu},i} \) are referred to the trigger and the same \( T_0 \) value is assigned to both clusters. To reduce the uncertainty from the determination of \( T_0 \) the difference
\[ \delta t_{1,2} = \delta t_1 - \delta t_2 \]
is used to determine the mass assignment to the tracks. The \( \pi \pi \) hypothesis is tested first, the distribution of \( \delta t_{\pi\pi} = \delta t_{1,\pi} - \delta t_{2,\pi} \) is shown in Figure 3 and Figure 4. A fair agreement is observed between data and simulation. The \( K_S \to \pi\mu\nu \) and \( K_S \to \pi e\nu \) distributions are well separated and the \( K^+K^- \) background is isolated in the tails of the distribution, however the signal is hidden under a large \( K_S \to \pi^+\pi^- \) background. To reduce the background a cut is applied:
\[ 1 \text{ ns} < |\delta t_{\pi\pi}| < 10 \text{ ns} \quad \text{for} \quad K_S \to \pi e\nu; \quad 1 \text{ ns} < |\delta t_{\pi\pi}| < 3 \text{ ns} \quad \text{for} \quad K_S \to \pi\mu\nu. \quad (3) \]

Then signal hypothesis is tested by assigning the pion and lepton mass to either track:
\[ \delta t_{\pi\ell} = \delta t_{1,\pi} - \delta t_{2,\ell} \quad \text{and} \quad \delta t_{\ell\pi} = \delta t_{1,\ell} - \delta t_{2,\pi} \quad \text{where} \quad \ell = e, \mu \]
The two-dimensional \( \delta t_{\pi\ell} \times \delta t_{\ell\pi} \) distribution for simulated signal events indicates that the correct mass assignment corresponds to the smaller absolute value of the two hypotheses. The distribution of \( \delta t_{\pi\ell} \times \delta t_{\ell\pi} \) is shown in Figure 5 and Figure 6 for data only. The distribution for the signal is narrow and peaked at zero while it is broader for the backgrounds. A final cut is applied:
\[ |\delta t_{\pi\ell}| < 1 \text{ ns} \quad \text{or} \quad |\delta t_{\ell\pi}| < 1 \text{ ns} \quad \text{for} \quad K_S \to \pi e\nu \quad |\delta t_{\pi\mu}| < 0.5 \text{ ns} \quad \text{or} \quad |\delta t_{\mu\pi}| < 0.5 \text{ ns} \quad \text{for} \quad K_S \to \pi\mu\nu. \quad (4) \]
After the mass assignment to the two tracks connected to the vertex the invariant mass of the charged secondary identified as the lepton is evaluated as

\[ m_\ell^2 = (E_{K_S, \text{tag}} - E_\pi - p_{\text{miss}})^2 - p_\ell^2 \]

with \( p_{\text{miss}}^2 = (\vec{p}_{K_S, \text{tag}} - \vec{p}_\pi - \vec{p}_\ell)^2 \). \( E_{K_S, \text{tag}} \) and \( \vec{p}_{K_S, \text{tag}} \) being the energy and momentum reconstructed using the tagging \( K_L \), and \( \vec{p}_\pi, \vec{p}_\ell \) the momenta of the pion and lepton track. The number of signal events is extracted with a fit to the \( m_\ell^2 \) distribution (shown in Figure 7 and Figure 8) with the MC shapes of three components: \( K_S \to \pi\ell\nu \), \( K_S \to \pi^+\pi^- \) and the sum of all other backgrounds. For \( K_S \to \pi\mu\nu \) the third component, which is peaked around \( m_\ell^2 \), is found to be a negligible value by the fit. Figure 9 and Figure 10 show the distribution of \( m_\ell^2 \) before and after the fit, and Table 1 and Table 2 present the result of the fit on \( m_\ell^2 \) and \( m_\mu^2 \), respectively.

5.2.1. Normalization sample The normalisation sample of \( K_S \to \pi\ell\nu \) events is selected by requiring \( 140 < p < 280 \text{ MeV} \) for both tracks. This requirement selects \((282.314 \pm 0.017) \times 10^6\) events with 97.4% efficiency and a purity of 99.9% as determined by simulation.
Figure 9. Distribution of $m_e^2$ with the fit superimposed.

Figure 10. Distribution of $m_\mu^2$ with the fit superimposed.

Table 1. Result of the fit to the $m_e^2$ distribution

| Fraction | Events       |
|----------|--------------|
| $\pi\nu$ | 0.87 49 652 ± 351 |
| $\pi^+\pi^-$ | 0.08 4 350 ± 392 |
| others   | 0.06 3 388 ± 384 |
| Total    | 57 389       |

Table 2. Result of the fit to the $m_\mu^2$ distribution

| Fraction | Events       |
|----------|--------------|
| $\pi\mu\nu$ | 0.23 7 223 ± 180 |
| $\pi^+\pi^-$ | 0.77 23 764 ± 270 |
| Total    | 30 987       |

The efficiency is measured using the preselected data in two different ways: directly on data sample correcting for the purities before and after the momentum cut, and using different subsample with different cuts on the vertex transverse position. The efficiencies are $\epsilon_{\pi\pi} = (96.657 \pm 0.002)\%$ and $\epsilon'_{\pi\pi} = (96.569 \pm 0.004)\%$, respectively. The two values agree to better than 1 per mill. The number of $K_S \rightarrow \pi^+\pi^-$ events is $N_{\pi\pi}/\epsilon_{\pi\pi} = (292.08 \pm 0.27) \times 10^6$.

5.3. $K_S \rightarrow \pi\nu$ measurement finalization

5.3.1. Determination of efficiencies. The efficiencies for the selection of the signal sample (SS) are determined with two different $K_L \rightarrow \pi\nu$ control samples (CS) and evaluated as

$$
\epsilon_{SS}^{\text{data}} = \epsilon_{CS}^{\text{data}} \times \epsilon_{SS}^{\text{MC}} \times \epsilon_{CS}^{\text{MC}} \times p_a / p_b,
$$

where $\epsilon_{CS}^{\text{data}}$ is the efficiency of the control sample, $\epsilon_{SS}^{\text{MC}}$ and $\epsilon_{CS}^{\text{MC}}$ are the efficiencies obtained from simulation for the signal and control samples, respectively, $p_b$ and $p_a$ are the MC purities before and after a given selection.

The $K_L \rightarrow \pi\nu$ decay [11, 12] is kinematically identical to the signal, the only difference being the much longer decay path. For the control sample the tagging is done with $K_S \rightarrow \pi^+\pi^-$ decays, selected in the same way as for the signal sample with the additional cut $|m_{\pi\pi} - m_{K^0}| < 15$ MeV to increase the purity. The radial distance of the second vertex, the $K_L$ vertex, is required to be smaller than 5 cm to match the signal selection, but greater than 1 cm, to minimise the interference in identifying the $K_L$ and $K_S$ vertices. After unbiased selections, the purity of the sample as determined from simulation is 95% for $K_L \rightarrow \pi\nu$ and 86% for $K_L \rightarrow \pi\mu\nu$. The total efficiency is found to be:

$$
\epsilon_{\pi\nu} = 0.0552 \pm 0.0005_{\text{stat}} \pm 0.0017_{\text{syst}} \quad \text{for} \quad K_S \rightarrow \pi\nu
$$
5.3.2. Systematic uncertainties Two main systematic uncertainties affect the measurement of $N_{\pi\mu\nu}$: BDT and time-of-flight selection, and the $m^2_{\mu}$ fit. The analysis is repeated varying the BDT cut of Eq. (2), the number of signal events is found stable and the rms value of the differences gives a relative uncertainty of 0.3%. The main source of uncertainty in the TOF selection is the cut on $\delta t_{\pi\pi}$ in Eq. (3) because the signal and background distributions in Figure 4 are steep and with opposite slopes; the subsequent selection on $\delta t_{\mu}$ in Eq. (4) has a minor effect. The resolution of the $\delta t_{\pi\pi}$ variable evaluated with simulation and $K_S \to \pi^+\pi^-$ data control samples is $\pm 270$ ps. The analysis is repeated varying the $\delta t_{\pi\pi}$ lower cut in the range 0.5–1.3 ns, the rms value of the differences gives a relative uncertainty of $\pm 3.0\%$. This is the main systematic uncertainty affecting the measurement.

5.3.3. $R_e$ The ratio $R_e$ in Eq. (1) results from several effects all depending on the global properties of the event: trigger, on-line filter, event classification, $T_0$ determination, $K_L$-crash and $K_S$ identification. The various contributions to $R_e$ are evaluated from simulation; the systematic uncertainties are evaluated by a comparison of data with simulation. Final result is:

$$R_e = 1.472 \pm 0.003_{\text{stat}} \pm 0.025_{\text{syst}}.$$  \hspace{1cm} (7)

5.4. Results

For $K_S \to \pi\nu\nu$, systematics are under finalization; a preliminary result shows total uncertainties at 1% level. For $K_S \to \pi\mu\nu$, from Eq. (1) with $N_{\pi\mu\nu} = 7223 \pm 180$, $N_{\pi\pi}/\epsilon_{\pi\pi} = (292.10 \pm 0.26) \times 10^6$, the values of the efficiencies in Eq. (6), $\epsilon_{\pi\mu\nu} = 0.0552 \pm 0.0018$, $R_e = 1.472 \pm 0.025$, and the value $B(K_S \to \pi^+\pi^-) = 0.69196 \pm 0.00051$ measured by KLOE [13], we derive the branching fraction

$$B(K_S \to \pi\mu\nu) = (4.56 \pm 0.11_{\text{stat}} \pm 0.17_{\text{syst}}) \times 10^{-4} = (4.56 \pm 0.20) \times 10^{-4}.$$  

This is the first measurement of this decay mode.

6. Summary

The KLOE-2 data taking ended in March 2018, after collecting 5.5 $fb^{-1}$. The total KLOE and KLOE-2 data sample consist of $\sim 8$ $fb^{-1}$, a unique data sample for typology and statistical relevance. Analysis are on going on KLOE and KLOE-2 data:

- Upper limit on $B(K_S \to 3\pi^0) < 2.6 \times 10^{-8}$ at 90% on 1.7 $fb^{-1}$
- First preliminary measurement of $B(K_S \to \pi\mu\nu) = (4.56 \pm 0.11_{\text{stat}} \pm 0.17_{\text{syst}}) \times 10^{-4}$ on 1.63 $fb^{-1}$
- Finalization of $B(K_S \to \pi\nu\nu)$ with preliminary uncertainties $\sim 1\%$

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