Form No. 24

# Measurement of the Rare Decay $K^+ \rightarrow \pi^+\nu\nu$ at the CERN SPS

## NA62 Project (*prolongation for* ***2022-2024***)

Theme 02-1-1096-2010/2022

**List of organizations and participants**

**Belgium:** Université Catholique de Louvain (**Louvain-La-Neuve**);
**Bulgaria:** University of Sofia St. Kliment Ohridski, Faculty of Physics **(Sofia)**;
**Canada**: TRIUMF, University of British Columbia **(Vancouver)**;
**Czech Republic**: Charles University (**Prague)**;
**Germany:** Johannes-Gutenberg-Universitat Mainz (**Mainz)**;
**Italy:** Università di Ferrara (**Ferrara)**, Universita e INFN (**Florence)**, Istituto Nazionale di Fisica Nucleare (INFN), Laboratori Nazionali di Frascati **(Frascati),** Universita e INFN (**Naples)**, Universita e INFN (**Padua)**, Universita e INFN (**Perugia),** Sezione di Pisa, INFN **(Pisa)**, Universita degli Studi di Roma Tor Vergata, Sezione di Roma Tor Vergata, INFN (**Rome)**, Universita e INFN, Roma I, Sezione di Roma I, INFN**(Rome)**, Universita e INFN (**Turin)**;
**Mexico**: Universidad Autónoma de San Luís Potosi, Instituto de Fisica (**San Luis Potosi)**;
**Romania**: Horia Hulubei National Institute of Physics and Nuclear Engineering (**Bucharest-Magurele)**;
**Russia:** Joint Institute for Nuclear Research – JINR (**Dubna)**, Institute for Nuclear Research RAS (**Moscow)**, Institute for High Energy Physics, Russian Federation State Research Centre (**Protvino)**;
**Slovakia**: Comenius University (**Bratislava)**;
**Switzerland:** Conseil Européen pour la Recherche Nucléaire – CERN (**Geneva)**
**United Kingdom:** University of Birmingham (**Birmingham)**, University of Bristol, H. H. Wills Physics Laboratory (**Bristol)**, University of Glasgow (**Glasgow)**, University of Liverpool, Oliver Lodge Laboratory (**Liverpool)**;
**United States of America:** Boston University (**Boston)**, George Mason University (**Fairfax)**, SLAC National Accelerator Laboratory (**Menlo Park)**, University of California Merced (**Merced)**, Brookhaven National Laboratory (BNL) (**Upton**).

**Laboratory of High Energy Physics:**

A.Baeva, D. Baygarashev, A. Belkova, S. Gevorkian, V. Gorbunova, L. Glonti, E. Goudzovski, D. Emelyanov, T. Enik, V.Falaleev, T. Mauei, V. Kekelidze, D.Kereibay, A.Korotkova, D.Madigozhin, M. Misheva, N. Molokanova, S.Movchan, I. Polenkevich, Yu. Potrebenikov, S. Shkarovskiy

**Project leaders:** Kekelidze V.D.(LHEP), Potrebenikov Yu.K. (LHEP)

DATE OF SUBMISSION OF PROPOSAL OF PROJECT TO SOD ________

DATE OF THE LABORATORY STC _________________ DOCUMENT NUMBER ______

DATE OF THE PROJECT FIRST APPROVAL by SC 24.09.2009

Form No. 25

PROJECT ENDORSEMENT LIST

# Measurement of the Rare Decay $K^+ \rightarrow \pi^+ \nu\nu$ at the CERN SPS

**NA62 Project (*prologation for 2022-2024*)**

Theme 02-1-1096-2010/2022

Project leaders: V Kekelidze, Yu. Potrebenikov

APPROVED BY JINR DIRECTOR

ENDORSED BY

JINR VICE-DIRECTOR

CHIEF SCIENTIFIC SECRETARY

CHIEF ENGINEER

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LABORATORY DIRECTOR

LABORATORY CHIEF ENGINEER

PROJECT LEADER

ENDORSED

RESPECTIVE PAC

**List of contents**

**Abstract**

The proposed project is a continuation of the four stages of NA62 project, implemented in VBLHEP JINR in 2010 - 2021. The goal of all stages of the project is the participation in realization of the NA62 experiment at SPS CERN, where a measurement of the very rare kaon decay $K^+ \to \pi^+ \nu\nu$ is planned to make a decisive test of the Standard Model (SM) by means of the 10%-precision measurement of the Cabibbo-Kobayashi-Maskawa (CKM) matrix parameter $V_{td}$.

Additionally, a series of precision measurements may be performed for the kaon rare leptonic decay modes in order to check the validity of the Standard Model and Chiral perturbation theory (ChPT) that provides a low energy approximation for the strong interactions description. Apart from that, there is a plan to search for the Goldstone fermion superpartner – pseudoscalar sgoldstino.

The strategy of the ongoing NA62 experiment is based on the measurement of the high energy $K^+$ decays in flight. In this case, the kaons production cross section is optimized as a function of the proton energy, and the photons detection is efficient due to their high energies in the laboratory system.

The JINR NA62 team consists of experienced physicists and young scientists. Prof. V. Kekelidze and D. Madigozhin possess the Doctor of Science degree, and eight other team members possess PhD degree. All of them have a vast experience obtained in other experiments on the kaon decay properties, including NA48, NA48/1 and NA48/2. Three members of the team continue to work on their PhD theses based on the NA48/2 data. Additionally, the team includes four young employees, who plan to prepare PhD theses based on the NA62 data.

The volume of the necessary funding for the years **2022-2024** from the JINR budget is **$515k .**

## 1. Introduction

The project goal is the participation in the NA62 experiment at SPS CERN, where a measurement of the very rare kaon decay $K^+\to\pi^+\nu\nu$ is planned to make a decisive test of the Standard Model (SM) by means of 10%-precision measurement of the Cabibbo-Kobayashi-Maskawa (CKM) matrix parameter $V_{td}$. The project is a continuation of the four stages of NA62 project, implemented in VBLHEP JINR in 2010 - 2021.

Using the Wolfenstein notation of CKM, the relationship between the parameters ρ and η may be represented by the unitarity triangle shown in Figure 1. The "golden modes" $K^0\to\pi^0\nu\nu$ and $K^+\to\pi^+\nu\nu$ give an opportunity to make a very sensitive tests of SM, as their probabilities are directly related to $\eta^2$ (height of triangle) and $(\rho - 1.4)^2 + \eta^2$. The SM predictions for these two decay rates have accuracy to 2% and 8% respectively, and in the case if significant deviations from the predictions will be observed, it will undoubtedly be the evidence of the phenomenon beyond the SM.

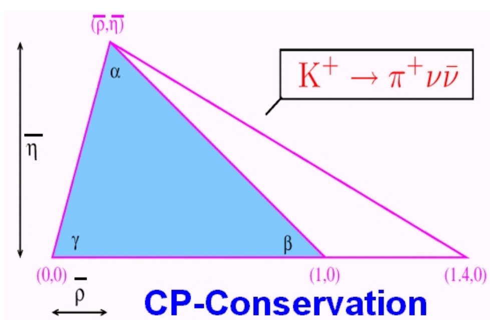


*Figure 1. The decay $K^+\to\pi^+\nu\nu$ is represented by the right segment of the triangle.*

The purpose of the NA62 experiment, a detailed description of which is given in [1,2,3,4], is to register about 100 events of $K^+\to\pi^+\nu\nu$ decay and to keep the total systematic uncertainty small. It will be a considerable improvement with respect to the currently available E787 and E949 result [5] based on just 7 golden mode events.

To this purpose, at least $2\times10^{13}$ $K^+$ decays are required, assuming a 10% signal acceptance and the branching ratio of $10^{-10}$. Small systematic uncertainty requires a rejection factor for generic kaon decays at the order of $10^{12}$, and the possibility to measure registration efficiencies and background suppression factors directly from the data.

Large kaon flux makes it possible to search for other rare kaon decays and to study their characteristics, including a check of the existence of Goldstone fermion superpartners [6-8]. A series of precision measurements may be performed for the kaon rare decay modes to check the validity of the Chiral perturbation theory (ChPT). Search for the rare decays forbidden or suppressed in the frameworks of SM opens a possibility to discover a new physics or to set new limits on the validity of SM and some its extensions. It includes the search for the light candidates to the dark matter that may be generated in rare kaon decays, including heavy neutral lepton [9].

## 2. State-of-the-art of the science case proposed

Prior to the NA62 experiment, most precise experimental results have been obtained by the E787 and E949 experiments at BNL by studying of stopped kaon decays [5]: $B(K^+\rightarrow\pi^+\nu\nu) = (1.73^{+1.15}_{-1.05})\times10^{-10}$. Apart from the NA62 experiment described below, no other measurements of this mode are currently conducted or planned. Existing gap between the theoretical precision and the large experimental error motivates a strong experimental effort. Significant new constraints can be obtained with a measurement of the rate of this reaction at the level of 10% or better.

The strategy of the ongoing NA62 experiment is based on the measurement of the high energy $K^+$ decays in flight. In this case, the kaons production cross section is optimized as a function of the proton energy, and the photons detection is efficient due to their high energies in the laboratory system. As a result, the $\pi^+\nu\nu$ signal acceptance was expected to be about 20 times higher than in the stopped kaon BNL experiments.

During the **previous implementation period of the project**, NA62 experimental setup has been constructed and tested in 2014 with CERN SPS beams. Experts from JINR and CERN have provided the construction and installation of the track spectrometer detectors designed and built during the two NA62 project stages completed in JINR earlier (in 2010-2012 and in 2013-2015).

After the spectrometer straw chambers installation into the NA62 experimental setup in 2014 (Fig. 2) their actual position has been measured, vacuum tests of straw detectors have been performed, gas supply system has been mounted. Four power supply modules (MPOD) have been installed, and their management interface integrated into the NA62 slow control system has been developed. A series of important methodical works has been performed for the spectrometer design and production [10-13].

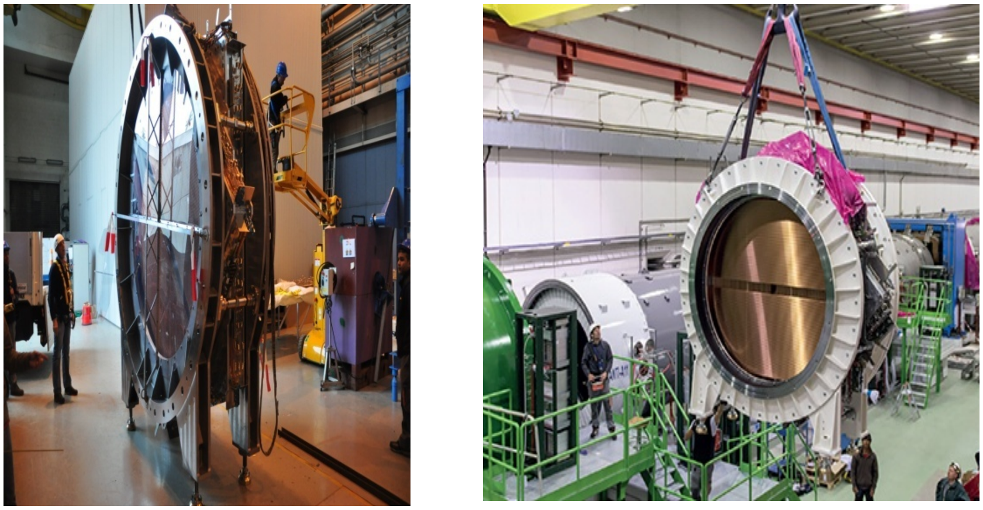

*Figure 2. Straw chamber assembled of 2 modules (left) and its installation into the NA62 experimental setup (right).*

During the NA62 experimental runs in 2016-2018 the JINR group members performed in total about 250 shifts on the experimental setup.

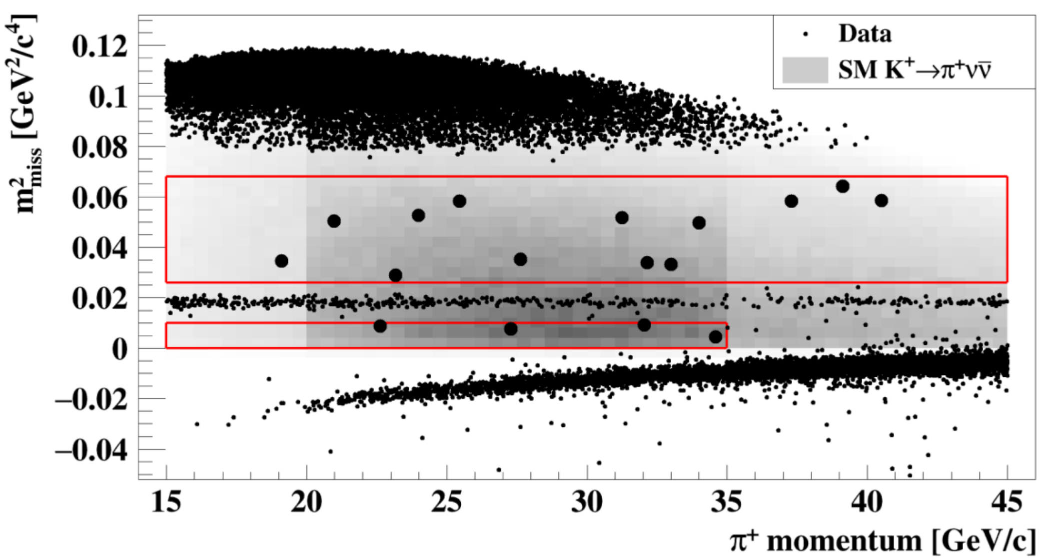


*Figure 2. Missing mass squared vs pion momentum for the $K^+ \to \pi^+ \nu\nu$ decay candidates selected from the NA62 data collected in 2018.*

NA48/2 and NA62 experimental data obtained in 2003 – 2018 were analyzed in 2019-2021 with the following main results:

- **The new NA62 result of the $K^+ \to \pi^+ \nu\nu$ decay study** based on the data collected in 2018 has been obtained [14]. The single event sensitivity is $1.11\times10^{-11}$, corresponding to 7.6 Standard Model events. 17 signal candidates are observed while the expected background is 5.3 events (see Fig. 2). Together with the 3 candidates registered earlier by NA62 in the 2016 and 2017 data [15,16], this leads to the most precise $K^+\to\pi^+\nu\nu$ branching ratio measurement $BR(K^+\to\pi^+\nu\nu) = (11.0^{+4.0}_{-3.5} \pm 0.3_{syst}) \times10^{-11}$, that is in agreement with the Standard Model expectation $(8.4 \pm 0.1)\times10^{-11}$.

- **On the basis of NA48/2 data**, a new upper limit on the rate of the lepton number violating decay $K\to\pi\mu^\pm\mu^\pm$ has been obtained [17], a first observation and study of the rare decay $K^\pm\to\pi^\pm\pi^0e^+e^-$ has been done [18], and a most precise combined $K_{e3}$ and $K_{\mu3}$ decays form factors measurement has been performed [19].
- **On the basis of NA62 data collected in 2007**, $\pi^0$ electromagnetic transition form factor slope parameter has been measured [20], and new upper limits have been set on the squared matrix element $|U_{\mu4}|^2$ (describing mixing between muon and hypothetical heavy neutrino) from the $K^+\to\mu^+\nu$ decays missing mass spectrum [21].
- **On the basis of NA62 data collected in 2015-2018**, new limits are established on the elements of the heavy neutrino mixing matrix $|U_{e4}|^2$ and $|U_{\mu4}|^2$ [22,23], and new limits are set on the hypothetical dark photon coupling to the ordinary photon [24].

## 3. Description of the proposed research

### 3.1 Subject of the research and methods

Reasearch activity proposed for the extension of the NA62 Project in JINR will be focused on the reaching the final goal of the ongoing NA62 experiment – nearly 10% precision measurement of the $K^+\to \pi^+\nu\nu$ branching ratio. JINR contribution to this result already includes the participation in the Spectrometer creation and maintaining. During the analysis stage, JINR group takes part in the detector calibration and common software development.

Additionally, NA62 collaboration investigate a series of the kaon rare decay modes. JINR group participates in the analysis of the four-lepton decays $K^+\to e^+\nu\mu^+\mu^-$, $K^+\to e^+\nu e^+e^-$, $K^+\to\mu^+\nu e^+e^-$ and $K^+\to\mu^+\nu\mu^+\mu^-$ (not yet observed) with the branching ratios of the order of $10^{-8}$. Their precision measurement will improve our knowledge of the ChPT parameters and will check its validity. Search for the forbidden modes $K^+\to e^-\nu\mu^+\mu^+$, $K^+\to\mu^-\nu e^+e^+$ will test the limits of SM.

Large statistics of kaon decays in NA62 provide us with a possibility to check the prediction [6] about the existence of Goldstone fermion superpartners — pseudoscalar sgoldstino *P*. The HyperCP experiment [7] has registered 3 decays $\Sigma\to \pi\mu^+\mu^-$ where the mass of P→ $\mu^+\mu^-$, if it exists, is 214.3 MeV. For NA62, the measurement of incoming $K^+$ momentum provides a possibility to reconstruct missing mass in the $K^+ \rightarrow \pi^+\pi^0 P$ decays with undetected pseudoscalar P [8].

A search for heavy neutral lepton (HNL) production in charged kaon decays is also foreseen on the basis of NA62 data. For example, Neutrino Minimal Standard Model [9] postulates three HNLs, explaining dark matter and baryon asymmetry of the universe. The idea of the search for HNL in NA62 is based on the missing mass distributions for $K^+\rightarrow e^+$ and $K^+\rightarrow \mu^+$ with the measured kaon and lepton momenta.

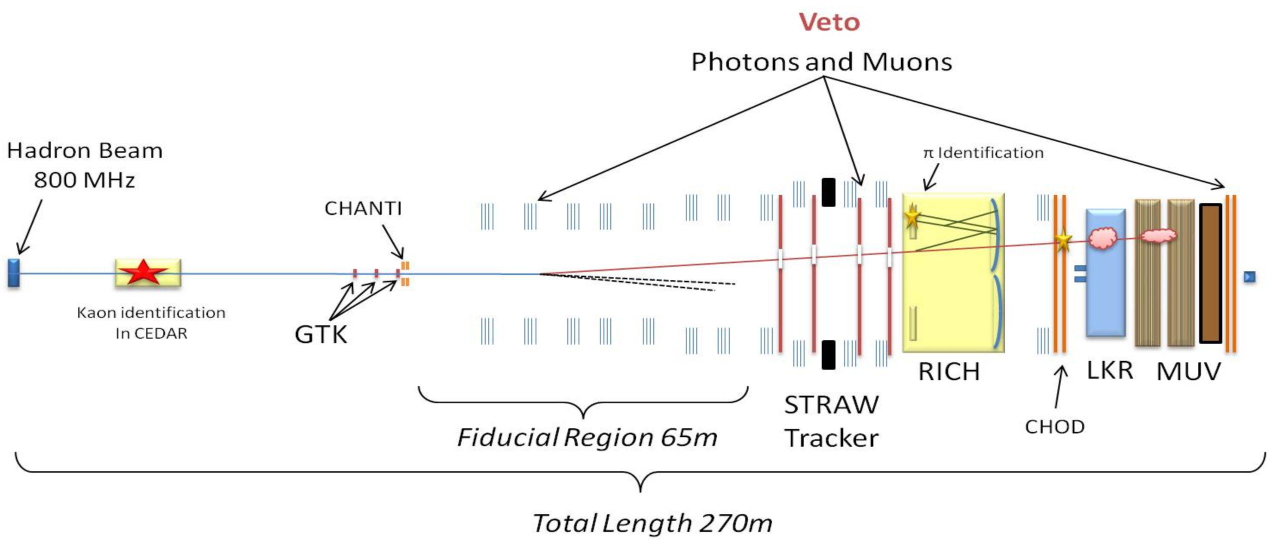


*Figure 3. Schematic view of the NA62 experimental setup.*

NA62 experimental setup (Figure 3) includes the following detector systems:

- **CEDAR** identifies the $K^+$ component in the beam with respect to the other beam particles by employing an upgraded differential Čerenkov counter.
- Gigatracker **(GTK)** consists of three Si micro-pixel stations measuring time, direction and momentum of the beam particles.
- **STRAW tracker** consists of 4 straw chambers. It measures the coordinates and momentum of secondary charged particles originating from the decay region. In order to minimize multiple scattering the chambers are built of ultra-light material and are installed inside the vacuum tank. The four Straw chambers are arranged around a large aperture dipole magnet (MNP33, black at the scheme), providing a vertical B-field of 0.36 T.
- **RICH detector** consists of 17m long radiator filled with Neon gas at 1 atm. allowing the separation of pions and muons between 15 and 35 GeV/c.
- A system of Photon-Veto detectors provides hermetic coverage of the decay region from zero to large (~50 mrad) angles. This is assured by: the high-resolution Liquid Krypton electromagnetic calorimeter (**Lkr**), the Intermediate Ring (**IRC**) and Small-Angle (**SAC**) Calorimeters and a series of 12 annular photon-veto (**LAV** or **Veto**) detectors.

- The Muon-Veto detectors (**MUV**) are composed of the two-part hadron calorimeter followed by the additional layer of iron and the transversally segmented hodoscope. This system provides redundancy in the detection of muons.

These detectors are complemented by “guard-ring” counters (**CHANTI**) surrounding the last GTK station, and the charged-particle hodoscope (**CHOD**), covering the acceptance and located between the RICH and the LKr. All the detectors are operated and inter-connected with a high-performance **trigger** and **data-acquisition** (**TDAQ**) system. The main detectors are described in details in [1,3].

The distribution of the missing mass square for $K^+$ and positively charged track is analyzed in assumption that the track is produced by $\pi^+$. The missing mass distribution for the $K^+\to\pi^+\nu\nu$ decay is shown in the left diagram of the Figure 4. The NA62 signal areas are chosen taking into account the resolution (Region I and Region II). The left diagram shows the background, that may be separated by means of kinematics, while the right one shows kinematically inseparable background suppressed by means of additional cuts.

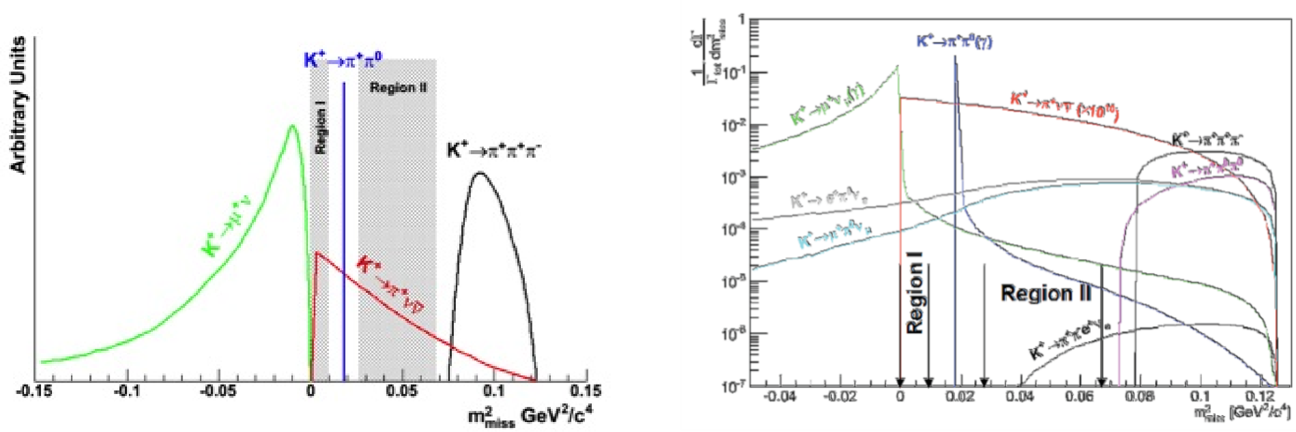


*Figure. 4. Missing mass* $m^2_{miss} = (P_K - P_{track})^2$ *distribution for the signal (red line) and background events. Background decay modes that may be separated from the signal by kinematics are shown on the left plot, while the inseparable background is on the right plot.*

There are also $K^+$ decay modes (with branching ratios > $10^{-5}$), for example, $K_{e4}$ ($K^+\to\pi^+\pi^-e^+\nu$), which can have a topology similar to the studied decay in cases when both the negatively charged pion and the charged lepton escape detection. So it is mandatory that the detector be rendered hermetic with respect to negatively charged particles. This is provided by the tracker chambers.

The experimental research methods rest upon the NA62 decay-in-flight technique based on the measurement of the high energy kaon decay products as well as on the incoming kaon kinematics registering. Fundamental kinematic relations are used to evaluate the events characteristics, while the statistical interpretation of the results rely upon the established mathematical tools and tested software. NA62 experimental setup described above is built during the previouse stages of the Project, and only its support and calibration are expected from the JINR group in future.

3.2 Accomplished groundwork

In October 2019 the experiment submitted Addendum 1 to P326 to the SPSC, proposing the continuation of the physics programme after LS2, and the first year of data taking has been approved. The FRC of November 2019 approved the budget for 2020, allowing us to ramp up the preparation for data taking after LS2.

During the physics NA62 run in 2016 a stable data taking was performed at the intensity of $13\times10^{11}$ protons per pulse on the target used for the kaon flux generation (40% of nominal intensity). The intensity was limited by the beam time structure that was leading to the increased maximum values of the beam intensity, that were much higher than it was expected. As a result, the backend electronics of some detectors was not able to process data at the peaks of intensity. Due to firmware upgrade, for NA62 runs in 2017-2018 the data taking was done at 60% of nominal intensity. Another essential reason for diminished statistical significance of NA62 currently achieved result is the unexpected size of upstream background, that will be suppressed in future by means of extra shielding and better kaon measurement.

Improvements to the radiation shielding were made prior to the 2018 data taking. The electronics racks for the KTAG, CHANTI and GTK cooling stations were equipped with additional concrete blocks. Neutron shielding (boron carbide) was added to electronics racks of the KTAG. In order to reduce the upstream background affecting the $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ analysis, the beam layout upstream of the decay volume were modified. The main modifications are: an optimized achromat layout, a 4th GTK station, and a new veto–counter system around the beam pipe. As a result, the upstream background is expected to be reduced by a factor 2–3.

A thorough study of sources of inefficiencies in the whole TDAQ system was undertaken, exploiting all the available recorded information. The study indicates that several sources contribute, and identified a few pieces of missing information which will be recorded to fully monitor all sources of downtime.

Since April 2019 efforts have been concentrated on improving the calibration procedures of several detectors, including the new energy calibration of the LKr using photons from $\pi^0$ decays developed by JINR and Perugia groups.

JINR contribution to the NA62 past and ongoing activities is quite essential. From the beginning of the project, JINR group together with CERN was responsible for the key detector creation – the NA62 Spectrometer (STRAW tracker). JINR contribution to the Spectrometer is defining in many aspects: R&D, MC simulation for design stage, straws geometry choise, frames design, straws production (more than 7000 in JINR), modules assembling. During the NA62 experimental runs in 2016-2018, a JINR group member (S. Shkarovskiy) was an official expert responsible for the Spectrometer performance and for the Spectrometer part of the Detector Control System (DCS).

3.3 Schedule of the proposed activities and potential risks

The proposed Project prolongation perion (2022-2024) is expected to be the period of NA62 data taking with the hardware, firmware and software improvements that will suppress upstream background and increase the signal acceptance due to possibility to relax some cuts. The complete total nominal NA62 statistics (~ 100 SM events) will be collected during the proposed phase.

The means required to participate in data taking and data analysis include educated manpower for the data analysis and for the NA62 Spectrometer maintaining as well as the travel expenses to participate in the NA62 runs and to attend some international conferences. No considerable extra equipment is expected to be provided by the participating teams.

The potential risks for the project extension period are much smaller than the risks foreseen from the very beginning of the project. Many problems related to the novel detector elements creation were considered in the Technical Design Document [2]. They have been solved finally, but it required a considerable delays of data taking, that is the main explanation why the NA62 goal is not achieved yet. JINR group was not responsible for the delays. 2014, 2015 and the most of 2016 were the setup building stage with a completely operational Spectrometer.

Moreover, two more problems have appeared without any scenarios (and this is the second reason why the NA62 aim is not achieved yet): unexpectedly high variations of the beam intensity from accelerator and the high level of upstream background.

Fortunately, the performed earlier analysis of 2016-2018 data show that no other risks of this kind can appear, and only essential improvements are expected. As a result, the goal of ~ 100 SM events will be almost definitely achieved with the run prolongation after the LS.

The realistic risks we could consider now include the following scenarios:

- There will be no NA62 run prolongation (say, due to pandemia). Spare strategy for this case:
  - other additional analyses of kaon rare decays with the available statistics.
- There will be not enough manpower for the fast finishing of all the additional analyses. Spare strategy:
  - we will try to attract even more talanted young people;
  - we will finish all analyses later in parallel with another stages of the project (currently we still work on the NA48/2 data collected in 2003/2004).

### 3.4 JINR group contributions and responsibilities for 2022-2024

The list of JINR group contributions and responsibilities includes:

- Fine calibration and alignment of straw detector on the basis of collected data;
- Participation in the LKr fine calibration based on $\pi^0$ decays;
- Improvement of the straw detector Monte Carlo simulation used for the main NA62 analysis;
- Participation in the analysis of rare background sources for $K^+ \to \pi^+ \nu\nu$;
- Analysis of the four-lepton decay modes of charged kaon;
- $K_{e3}\gamma$ analysis;
- $K^+ \to \pi^+ \gamma e^+ e^-$ analysis;
- $K^+ \to \pi^+ \pi^- \mu^+ \nu$ analysis;
- $K^\pm \to \pi^0 \pi^0 \mu^\pm \nu$ analysis (NA48/2 data);
- Search for the light sgoldstio signatures;
- Diagnostics and necessary repair of the Spectrometer straw chambers and their low and high voltage power supply;
- Participation in R&D for a new straw module creation;
- Participation in the NA62 data taking runs in 2022-2024;
- Support the NA62 Spectrometer during the data taking runs in 2022-24.

For the project prolongation period the participation of the group will include:
- Technical hardware support of the Spectrometer (3 persons).
- Spectrometer on-call expert during the data taking, Detector Control System development and maintenance (1).
- Software for the data quality control development and maintenance (2).
- Participation in the MC development in the Spectrometer part (1).
- Physical analysis: specific background sources for $\pi\nu\nu$, additional physical goals for our group (10 persons with a different intensity).

### 3.5 Participants publications, PhD theses and presentations at conferences

8 journal NA62 papers [15,16,18,23,24,25,26,27] have been published with the Dubna group participation in 2019-2021 (16 co-authors from JINR). In 3 of them [18,23,25] the Dubna group members are the principal co-authors.

Two PhD theses text preparation is in progress. Obtained results in 2019-2021 were presented at the international conferences, including 11 presentations given by the members of JINR group [28-38].

A series of scientific works of Dubna group “Study of rare and search for forbidden decays of charged kaons” was awarded a second JINR prize (2019) in the nomination of experimental research papers.

## 4. Estimation of human resources

The following Table lists the NA62 JINR group members with their roles (in addition to the data taking shifts) and participation.

| Name | FTE | Work in addition to common duties (shifts) |
|---|---|---|
| D. Baygarashev | 1.0 | Data quality control, calibration, physical analysis |
| A. Baeva | 1.0 | Physical analysis |
| A. Belkova | 0.5 | Documentation preparation |
| S. Gevorkian | 1.0 | Theory of rare decays, MC models development |
| L. Glonti | 0.2 | Spectrometer calibration and performance checks. |
| V. Gorbunova | 0.5 | Documentation preparation |
| E. Goudzovski | 0.1 | MC development, analysis, coordination |
| D. Emelyanov | 1.0 | Software tools development, analysis |
| T. Enik | 0.3 | Hardware development and support |
| V. Kekelidze | 0.1 | Project leader |
| D. Kereibay | 1.0 | Physical analysis |
| A.Korotkova | 0.7 | Physical analysis |
| D.Madigozhin | 1.0 | MC development, data quality control, analysis |
| T. Mauei | 1.0 | Detector calibration |
| M. Misheva | 0.2 | Physical analysis |
| N. Molokanova | 0.9 | Data quality control, detector calibration |
| S. Movchan | 0.2 | Hardware development and support |
| I. Polenkevich | 0.5 | Physical analysis |
| Yu. Potrebenikov | 0.5 | Project leader |
| S. Shkarovskiy | 1.0 | DCS development, hardware support, analysis |
| V. Falaleev | 0.2 | Slow control, DCS development, hardware support |
| **TOTAL FTE** | **12.9** | |

Form No. 26

### 5. Schedule proposal and resources required for the implementation of the Project NA62 ( "Measurement of the Rare Decay $K^{+} \to \pi^{+} \nu \nu$ at the CERN SPS")

| Expenditures, resources, financing sources | | | Costs (k$) Resource requirements | Proposals of the Laboratory on the distribution of finances and resources | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 1st year | 2nd year | 3rd year | 4th year | 5th year |
| Expenditures | | Main units of equipment, work towards its upgrade, adjustment etc. | 70 | 30 | 35 | 5 | | |
| | | Construction/repair of premises | | | | | | |
| | | Materials | 190 | 70 | 75 | 45 | | |
| Required resources | Standard hour | Resources of<br>– Laboratory design bureau;<br>– JINR Experimental Workshop;<br>– Laboratory experimental facilities division;<br>– accelerator;<br>– computer<br>Operating costs. | | | | | | |
| Financing sources | Budgetary resources | Budget expenditures including foreign-currency resources. | 515 | 200 | 200 | 115 | | |
| | External resources | Contributions by collaborators.<br>Grants.<br>Contributions by sponsors.<br>Contracts.<br>Other financial resources, etc. | | | | | | |

PROJECT LEADER

Form No. 29

**6. Estimated expenditures for the Project NA62 (Measurement of the Rare Decay $K^+ \rightarrow \pi^+ \nu\nu$ at the CERN SPS")**

| | Expenditure items | Full cost | 1st year | 2nd year | 3rd year |
|---|---|---|---|---|---|
| | Direct expenses for the Project | | | | |
| 1. | Accelerator, reactor, h | | | | |
| 2. | Computers, h | 3000 | 1000 | 1000 | 1000 |
| 3. | Computer connection, k$ | 15 | 5 | 5 | 5 |
| 4. | Design bureau, standard hour | 780 | 480 | 300 | |
| 5. | Experimental Workshop, st. hour | 1000 | 500 | 500 | |
| 6. | Materials, k$ | 70 | 30 | 35 | 5 |
| 7 | Equipment, k$ | 35 | 15 | 10 | 10 |
| 8. | Operational costs, k$ | 105 | 35 | 35 | 35 |
| 9. | Payments for agreement-based research, k$ | | | | |
| 10. | Travel allowance, k$, including: | 290 | 115 | 115 | 60 |
| | a) non-rouble zone countries | 275 | 110 | 110 | 55 |
| | b) rouble zone countries | 15 | 5 | 5 | 5 |
| | c) protocol-based | | | | |
| | Total direct expenses | 515 | 200 | 200 | 115 |

PROJECT LEADER

LABORATORY DIRECTOR

LABORATORY CHIEF ENGINEER-ECONOMIST

## 7. Strengths, Weaknesses, Opportunities, Threats

The strengths of the project extension include the following:

- fundamental importance of the scientific program;
- fully operating NA62 detector setup built with the JINR essential participation;
- a large amount of experimental data collected in 2016-2018;
- a strong support for the data taking prolongation from CERN side;
- experience in analysis of senior participants of the JINR team;
- young participants who will in future bring the best CERN practice into JINR projects;

Main weakness is caused by the temporary difficulties of transition from the mainly hardware activity to the data analysis stage that is overlaid with the lasting NA62 Spectrometer-related duties. This weakness is overcomed by means of the young participants training for the data analysis exploiting the existing experience of the other group members obtained earlier in the NA48/2 experiment.

The non-trivial opportunities of the project are the improved measurements of some rare decay modes based on the large statistics of kaon decays. Also there is a chance to find new physics in the case if new results will be incompatible with SM. Additionally, the participation in software development and detector calibration for NA62 will increase the qualification of young participants that may be needed in other JINR experiments.

No ongoing competition is known currently in the measurement of the charged kaon golden mode. So there are no threats to the project extension scientific importance.

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# Appendix

**Referee report on the Proposal of prolongation of the project**
**“Measurement of the rare decay $K^+\to\pi^+\nu\nu$ at the CERN SPS (NA62)”**

Probability of the rare decay $K^+\to\pi^+\nu\nu$ (of the order of $10^{-10}$) is directly related to the CKM matrix parameters defining the size of CP violation. Theoretically clean, this decay gives a possibility to discover a statistically significant deviation from the Standard Model and to open a new physics domain.

NA62 experiment at CERN SPS aims to measure the branching ratio of the $K^+\to\pi^+\nu\nu$ decay with a precision of the order of 10%, that requires extraordinary experimental efforts. First of all, the charged pion track must be measured with a high precision in conditions of minimum Coloumb scattering. So the key element of the NA62 detector is the straw-based magnetic spectrometer, that is made of light drift tubes. JINR group together with the dedicated CERN team were responsible for this spectrometer development, design and production.

After the spectrometer installation in 2014 and commissioning in 2015, the physical data taking was done in 2016-2018. During the LHC Long Shutdown period in 2019-2020 the experiment entered the stage of the physical data analysis. And JINR group is currently participating in the extraction of the physical results from the collected data, including the additional studies of the rare four-lepton decays of charged kaons.

During the period of 2019-2021 a series of works have been done by JINR group, and some important results have been obtained. A first observation and study of the rare decay $K^\pm\to\pi^\pm\pi^0e^+e^-$ has been done, new upper limits have been set on the squared matrix elements $|U_{\mu4}|^2$and $|U_{e4}|^2$, and new limits are set on the hypothetical dark photon coupling to the ordinary photon. Dubna group was awarded a second JINR prize in 2019 for the study of rare decays of charged kaons.

But the most important achievement is the NA62 result of the $K^+\to\pi^+\nu\nu$ decay study based on the data collected in 2016-2018. 17 signal candidates are observed in data collected in 2018. Together with the 3 candidates registered by NA62 in the 2016 and 2017, this leads to the most precise $K^+\to\pi^+\nu\nu$ branching ratio measurement $BR(K^+\to\pi^+\nu\nu) = (11.0^{+4.0}_{-3.5} \pm 0.3_{syst} \times 10^{-11}$that is in agreement with the Standard Model expectation. JINR group participates in the analysis of background decay modes, software development, detector calibration and maintaining.

During the future data taking period, starting from 2021, NA62 collaboration plans to reach its projected statistics (~ 100 events) and precision (~ 10%) for the main goal branching fraction measurement. No competition is known currently in the measurement of the same decay mode.

Dubna group includes now few more young participants working on the data analysis, that will be an excellent school for them.

Accomplished results are adequate to the financial expenses allocated for the project. I support an approval of the report related to the period of 2019-2021. The ongoing and planned works are adequate to the financing to be allocated for the project in 2022-2024, and I would recommend to prolongate the NA62 project in JINR for the next 3-year period.

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**Report on the request for prolongation of the project**

**"Measurement of the rare decay $K^+ \to \pi^+ \nu\nu$ at the CERN SPS (NA62)"**

The NA62 project continues a series of experiments to study kaon decays and to provide precise tests of the Standard Model, to gain new knowledge about the CP-violation nature and to search for the occurrence of new physics beyond the SM. The project was started in 2010 aimed to register 100 events of a very rare kaon decay $K^+ \to \pi^+ \nu\nu$. Assuming $10^{-10}$ branching ratio, the experimental facility should ensure the fulfilment of two main tasks – suppression of the background and the usage of a high intensity unseparated $K^+$ beam.

The main element of the proposed experimental facility is the magnetic spectrometer with tracker detectors produced using the straw tube technology. The JINR team made a great contribution to the construction, manufacturing and commissioning of the straw tube detectors. The facility was tested during the autumn 2014 run with CERN SPS beams. In 2016, data taking was started and 20 signal candidates were registered by the NA62 collaboration before the CERN shut down. This result alone leads to the most precise branching ratio measurement $BR(K^+ \to \pi^+ \nu\nu) = (11.0^{+4.0}_{-3.5} \pm 0.3_{syst}) \times 10^{-11}$.

Additionally, the NA62 collaboration studies a series of rare kaon decay modes. The JINR group also participates in the analysis of several four-lepton decays with branching ratios of the order of $10^{-8}$. Their precision measurement will broaden our knowledge of the ChPT parameters and verify its validity. The search for the forbidden modes will test the limits of the SM.

Large scale statistics of kaon decays together with high accuracy measurements allow to search for other rare kaon decays to check the existence of a supersymmetric particle sgolstino, to search for new light candidates for the dark matter, to study the possible heavy neutral lepton production and to verify the validity of the Chiral perturbation theory.

During the last period of the project, with the significant participation of the JINR group, a new upper limit on the rate of the decay violating the lepton number $K \to \pi\mu^\pm\mu^\pm$ has been obtained, the first observation and study of the rare decay $K^\pm \to \pi^\pm\pi^0 e^+ e^-$ has been done, and the most precise measurement of the combined form factors of $K_{e3}$ and $K_{\mu 3}$ decays has been performed. New limits have been established on the elements of the heavy neutrino mixing matrix $|U_{e4}|^2$ and $|U_{\mu 4}|^2$.

The obtained results were presented at many international conferences by JINR participants. Three papers were prepared by JINR principial co-authors.

I observe that currently the results of the JINR group are clearly visible in methodological and scientific fields. Based on the proposal to prolong the project, I conclude that the JINR team is fully integrated into the preparation of the NA62 experiment, data collection and analysis.

I consider the required financial support, which should ensure the activity of the JINR group and cover the expenses for the implementation of the experiment by the JINR side, to be justified and adequate. I support the approval of the project prolongation.

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