Appendix 1

Project Form No. 24

Search for new physics in the lepton sector

Поиск новой физики в лептонном секторе

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DATE OF SUBMISSION OF PROPOSAL OF PROJECT TO SOD ________

DATE OF THE LABORATORY STC ________ DOCUMENT NUMBER ________

STARTING DATE OF PROJECT 2021

(FOR EXTENSION OF PROJECT — DATE OF ITS FIRST APPROVAL) 2015

Date of the Lab seminars 12.03,2019, 9.10.2019, 10.10.2019

Appendix 2

Form No. 25

PROJECT ENDORSEMENT LIST

Search for new physics in the lepton sector

V.V.Glagolev, Z.Tsamalaidze

APPROVED BY JINR DIRECTOR

ENDORSED BY

JINR VICE-DIRECTOR

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CHIEF ENGINEER

HEAD OF SCIENCE ORGANIZATION DEPARTMENT

LABORATORY DIRECTOR

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PROJECT LEADERS

PROJECT DEPUTY LEADERS

ENDORSED

RESPECTIVE PAC

Search for new physics in the lepton sector

Поиск новой физики в лептонном секторе

Table of Contents

Abstract

Charged-lepton flavour-violating (cLFV) processes offer deep probes for new physics with discovery sensitivity to a broad array of new physics models - SUSY, Higgs Doublets, Extra Dimensions, and, particularly, models explaining the neutrino mass hierarchy and the matter- antimatter asymmetry of the universe via leptogenesis. The most sensitive exploration of cLFV is provided by experiments that utilize high intensity muon beams to search for cLFV $\mu \to e$ transitions: a muon decaying into an electron and a photon, $\mu^+ \to e^+\gamma$ (MEG experiment at PSI); a muon decaying into three electrons $\mu^+ \to e^+e^-e^+$ (Mu3e experiment at PSI); and the coherent neutrinoless conversion of a muon into an electron in the field of a nucleus, $\mu^- \mathrm{N} \to e^- \mathrm{N}$ (Mu2e experiment at Fermilab and COMET experiment at J-PARC).

Scientists from JINR are participating successfully in the preparation stage of the Mu2e, COMET and MEG-II experiments. For Mu2e experiment JINR colleagues will continue to create CRV system, to perform E-cal front-end electronic tests, establish remote Control room, participate in data analysis and probably participate in the detector assemble and maintenance. For MEG-II experiment our scientists will provide operation of JINR computer cluster, perform simulation, data analysis, creation of event display and support drift chamber operation. For COMET experiment JINR staff will produce all set of 5 mm straw tubes, participate strongly in the creation of straw-tracker, calorimeter and CRV system with further data analysis contribution.

During the 2015 – 2019 period of the projects (Mu2e and COMET), 44 papers with significant participation of JINR scientists concerning these experiments were published, more than 9 talks at international conferences and meetings were presented. The requested project budget is 1258 kUSD for 2021-2023.

Аннотация

Процессы с нарушением лептонного числа в секторе заряженных лептонов (cLFV), обеспечивают весомый поиск новой физики с чувствительностью к параметрам широкого спектра новых физических моделей - SUSY, дублетов Хиггса, дополнительных размерностей и, в частности, моделей, объясняющих иерархию масс нейтрино и асимметрию материи - антиматерии Вселенной через лептогенез. Наиболее чувствительное исследование cLFV обеспечивается экспериментами, которые используют высокоинтенсивные мюонные пучки для поиска переходов cLFV мюона в электрон: $\mu^+ \to e^+\gamma$ (эксперимент MEG в PSI); $\mu^+ \to e^+e^-e^+$ (эксперимент Mu3e в PSI), и когерентная безнейтринная конверсия мюона в электрон в поле ядра $\mu^-\mathrm{N} \to e^-\mathrm{N}$ (Mu2e эксперимент в лаборатории Ферми и эксперимент COMET в J-парк).

Ученые ОИЯИ успешно участвуют в подготовительном этапе экспериментов Mu2e, COMET и MEG-II. Для эксперимента Mu2e коллеги из ОИЯИ продолжат создавать мюонную вето-систему (CRV), проводить электронные тесты “передней” электроники для калориметра, создадут комнату мониторирования эксперимента для проведения удаленных смен, будут участвовать в анализе данных и, возможно, участвовать в сборке и обслуживании детектора. Для эксперимента MEG-II наши ученые обеспечат работу компьютерного кластера ОИЯИ, примут участие в моделировании, анализе данных, создадут on-line монитор отображения событий и примут участие в обеспечение эффективной работы дрейфовой камеры. Для эксперимента COMET сотрудники ОИЯИ изготовят весь комплект 5-миллиметровых straw-трубок, примут активное участие в создании всего трекера установки, калориметра и вето-системы CRV, анализе данных.

В течение 2015-2019 годов проектов (Mu2e и COMET), было опубликовано 44 работ, касающиеся этих экспериментов, с решающим участием ученых ОИЯИ, более 9 докладов были представлены на международных конференциях и совещаниях. Запрашиваемый бюджет проекта составляет 1258 k$ на 2021-2023 годы.

Introduction

Charged-lepton flavour-violating (cLFV) processes provide an unique discovery potential for physics beyond the Standard Model (BSM). These cLFV processes explore new physics parameter space in a manner complementary to the collider, dark matter, dark energy, and neutrino physics programmes.

Current limits for cLFV $\mu \rightarrow e$ transitions are in the 10^{-12} – 10^{-13} range and probe effective new physics mass scales above 10^3 TeV/c^2. Next-generation experiments at MEG-II, Mu2e and COMET expect to improve these sensitivities by as much as four orders of magnitude on the timescale of the mid-2020s. This dramatic improvement in sensitivity offers genuine discovery possibilities in a wide range of new physics models with SUSY, Extra Dimensions, an extended Higgs sector, lepto-quarks, or those arising from GUT models.

Beginning in the latter half of the next decade, upgrades to the beamlines at PSI, Fermilab,and J-PARC offer the possibility to further explore this parameter space. Improvements in sensitivity by an additional factor of 10-100 are possible with: the PIP-II linac at Fermilab to enable an upgraded Mu2e (Mu2e-II); an increased intensity at J-PARC to enable an upgraded COMET (Phase-II). A next-generation MEG experiment is also being explored. Significant JINR team participation in the design, construction, data taking, and analysis will be important to the success of these experiments and represents a prudent investment complementary to searches at colliders.

JINR staff will continue to takes part in the further preparation, operation of the above mentioned experiments and in the data analysis as well. More specific plans are:

1. for Mu2e experiment to participate hardly in production and tests of the Cosmic Ray Veto (CRV) modules; to perform RnD on creation of the solar blind photodetectors for BaF2 crystals for Mu2e-II; to create remote control room at JINR to take shifts; to participate in the assemble and maintenance of the CRV and calorimeter (if possible) and further data analysis
2. for MEG-II experiment to participate hardly in the DAQ development including cross platform event display; to provide JINR computer cluster for simulation, data storage and data analysis; maintenance of the cylindrical drift chamber; participation in the simulation and data analysis
3. for COMET experiment to participate hardly in design and creation of the straw tracker stations with 10 mm straw for COMET phase-I; participate in LYSO crystals QA tests; participation in the CRV design and construction; assemble and maintenance of the COMET setup; participation in shifts, simulation and data analysis; RnD and production of the 5 mm straw for 1-st and 2-nd phase of COMET experiment.

State-of-the-art of this scientific problem

Historically, flavour-changing neutral currents have played a significant role in revealing details of the underlying symmetries at the foundation of the SM. In the SM there is no known global symmetry that conserves lepton flavour. The discoveries of quark mixing and neutrino mixing, each awarded Nobel Prizes, provided profound insights to the underlying physics. Motivated by these past successes, there exists a global programme to explore cLFV processes providing deep, broad probes of BSM physics.

The objective is to search for evidence of new physics beyond the SM using cLFV processes in the muon sector. These processes offer powerful probes of BSM physics and are sensitive to effective new physics mass scales of 10^3-10^4 TeV/c^2, well beyond what can be directly probed at colliders. Over the next years, currently planned experiments in Europe, the US, and Asia will begin taking data and will extend the sensitivity to cLFV interactions by orders of magnitude. Further improvements are possible and new or upgraded experiments are being considered that would utilize upgraded accelerator facilities at PSI, JPARC and Fermilab and could begin taking data in the 2025-2030 timeframe.

Flavour violation has been observed in quarks and neutrinos, so it is natural to expect flavour violating effects among the charged leptons as well. In fact, once neutrino mass is introduced, the SM provides a mechanism for cLFV via lepton mixing in loops. However, the rate is suppressed by factors of $\left(\Delta m_{ij}^2 / M_w^2\right)^2$, where Δm_{ij}^2 is the mass difference squared between i^{th} and j^{th} neutrino mass eigenstates, and is estimated to be extremely small, for example BF ($\mu \rightarrow e\,\gamma$) ~ 10^{-54} [1]. Many extensions to the standard model predict large cLFV effects that could be observed as new experiments begin data taking over the next five years. Significant improvements are expected across a wide variety of cLFV processes (e.g. $\tau\rightarrow\mu\mu\mu$, $\mu\gamma$, or $e\gamma$; $\mu\rightarrow e\gamma$, eee; $\mu N\rightarrow eN$; Z or $H^0\rightarrow e\mu$, $e\tau$, or $\mu\tau$; $K_L\rightarrow e\mu$). The largest improvements are expected in experiments that search for cLFV transitions using muons.

Experimentally, there are three primary muon-to-electron transitions used to search for cLFV: a muon decaying into an electron plus a photon, $\mu^+ \rightarrow e^+\gamma$; a muon decaying into three electrons, $\mu^+ \rightarrow e^+e^-e^+$; and direct muon-to-electron conversion via an interaction with a nucleus, $\mu^-\mathrm{N} \rightarrow e^-\mathrm{N}$. These three $\mu\rightarrow e$ transitions provide complementary sensitivity to new sources of cLFV since the observed rates will depend on the details of the underlying new physics model. For example, for models in which cLFV rates are dominated by γ-penguin diagrams, the $\mu\rightarrow e\gamma$ transition rate is expected to be ~ 10^2 times larger than the $\mu\rightarrow$ eee and $\mu N\rightarrow eN$ rates. On the other hand, if the cLFV rates are dominated by Z- or H-penguin diagrams, or if tree level contributions are allowed (e.g. as in some lepto-quark or Z' models), then the $\mu\rightarrow e\gamma$ rate is suppressed and $\mu\rightarrow$eee and $\mu N\rightarrow eN$ rates can instead be largest. Thus, a programme with experiments exploring all three muon cLFV transitions maximizes the discovery potential and offers the possibility of differentiating among various BSM models by comparing the rates of the three transitions [2], [3].

Searches for $\mu\rightarrow$ e transitions have been pursued since 1947 when Pontecorvo first searched for the $\mu\rightarrow e\gamma$ process. Since then, the sensitivity has improved by eleven orders of magnitude via a series of increasingly challenging experiments. The current best limits for the three $\mu\rightarrow$ e transitions are BF ($\mu^+ \rightarrow e^+\gamma$) < 4.2x$10^{-13}$ [4], BF ($\mu^+ \rightarrow e^+e^-e^+$) < 1x$10^{-12}$ [5], $R_{\mu e}$ (Au) < 7x10^{-13} [6] at 90% CL, where $R_{\mu e}$ is the $\mu\rightarrow$e conversion rate normalized to the rate of ordinary muon nuclear capture. Currently planned experiments in Europe, the US, and Asia will provide sensitivities well beyond these existing limits. The MEG experiment at PSI has recently completed an upgrade and expects to extend the $\mu^+ \rightarrow e^+\gamma$ sensitivity by about an order of magnitude. The COMET experiment under construction at J-PARC will extend the sensitivity to $\mu^-\mathrm{N} \rightarrow e^-\mathrm{N}$ by about two orders of magnitude by the early-2020s, while the Mu2e experiment under construction at Fermilab will extend the sensitivity by about four orders of magnitude by the mid-2020s

As the charged counterpart of neutrino oscillations, cLFV plays a significant role in most of the BSM models seeking to explain the neutrino mass hierarchy and the universe's matter anti-matter asymmetry generated through leptogenesis. The cLFV measurements thus have considerable synergy with the neutrinoless double beta decay and neutrino oscillation research programmes. For example, there is a large class of models (see e.g. [7]) proposed to explain the smallness of the neutrino mass. These typically involve extensions to the Higgs sector and the existence of heavier neutrino partners, the properties of which - sterile or non-sterile, Dirac or Majorana, and the mass-scale of the neutrino partners - depend on the model. These heavy neutrino partners typically also play a role in generating a matter anti-matter asymmetry. The majority of these models predict large cLFV effects, and the comparison of cLFV and neutrino measurements together becomes a strong constraint on the model type and its parameters. Indeed, in the most natural models, where the neutrino partners are extremely massive, these measurements are one of the few portals into GUT-scale physics. In the Inverse Seesaw models [8], right-handed neutrinos with masses in the TeV-scale are produced that are potentially observable at the LHC. The present LHC limits are below 1 TeV whereas Mu2e and COMET will extend this sensitivity to 2 TeV. More generally Mu2e, COMET, and Mu3e till have a sensitivity for RH neutrinos up to masses of a few PeV, well beyond the direct detection limit of the LHC.

The μ→ e experiments also provide complementary information regarding the Majorana nature of neutrinos via the $\mu^- \to e^+$ transition: $\mu^- \mathrm{N}(Z,A) \to e^+ \mathrm{N}(Z-2,A)$. This transition violates both lepton number and lepton flavour and can only proceed if neutrinos are Majorana. This search channel comes for “free" in the Mu2e and COMET experiments. The Mu2e and COMET sensitivity to Majorana neutrinos will significantly extend beyond the current best limit[9] with $\langle m_{e\mu} \rangle$ effective Majoarna neutrino mass scale sensitivity down to the MeV region surpassing the $\langle m_{\mu\mu} \rangle$ sensitivity in the kaon sector which is limited to the GeV region [10].

Description of the proposed research

The same basic experimental methodology is employed in searches for these cLFV μ→ e processes. The experiment beamline begins by colliding protons onto a production target to produce low momentum pions. The resulting pions are either transported through a decay volume or directly stopped inside the target, and their decay muons are collected. These experiments require low momentum muons, typically with momenta less than 50 MeV/c, in order to stop them in thin targets at the center of the experimental apparatus. At these low momenta, muons stop in a few mm or less of material. To reach the target sensitivities requires high-intensity muon beams, > 10^8 stop- μ/s. The detector apparatus is designed to precisely determine the energy, momentum, and timing of particles originating from the muon stopping target. Because these experiments aim for such extreme sensitivities, their apparatus are customized to the final state of interest.

1. Mu2e experiment

The Mu2e experiment [11] is depicted in Fig. 1. The graded high-field pion production solenoid collects and focuses low-momentum pions towards the muon transport solenoid, which is an “S”-shaped magnet with a total path length of about 13 meters. The muon transport solenoid includes a set of collimators for momentum and charge-selection to provide ~10^{10} stop-μ^-/sec using 8 kW of 8 GeV protons from the Fermilab Booster delivered in pulses spaced 1.7μs apart. The detector solenoid provides a graded magnetic field in the upstream region, which houses the stopping target, and a near constant magnetic field in the downstream region, which houses the active detector elements. A low-mass tracking system consisting of approximately 21k thin aluminized-mylar straws [12] and a calorimeter consisting of two annular disks of

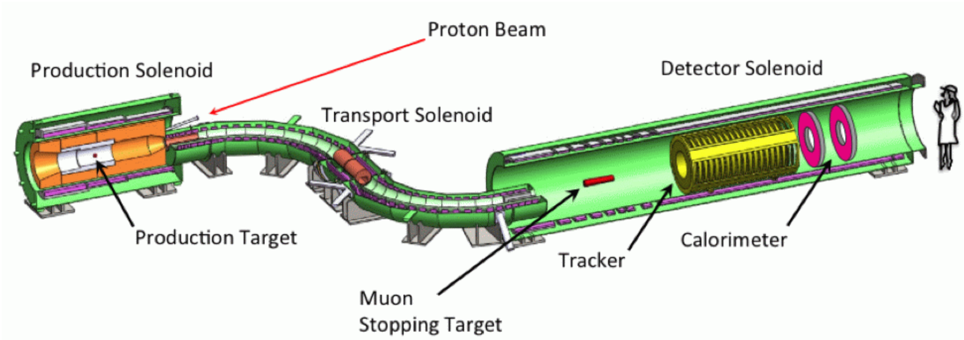

Figure 1: Schematic of the Mu2e experiment. A cosmic-ray veto system, and monitors for the proton beam and muon beam are not shown.

pure CsI crystals [13] precisely measure the timing, energy, and momenta of particles originating from the stopping target. The apparatus is shadowed on the outside by a large, scintillator-based cosmic-veto system. Ancillary systems are used to monitor the quality and intensity of the proton and muon beams. Construction of the solenoids and all the detector sub-systems has begun. Commissioning is expected to begin in 2022. After first phase of operation the projected sensitivity is $R_{\mu e} < 8x10^{-17}$ at 90% CL [11]. This sensitivity can be improved by at least a factor of 10 using a higher intensity proton beam and upgrading the Mu2e apparatus.

JINR contribution

At the beginning Project time Mu2e collaboration was aimed at creating an e.m. calorimeter on LYSO crystals and a lot of corresponding RnD were performed by JINR scientists [d2][d3]. However due to the rise in price of LYSO crystals it was decided to use CsI crystals in the first phase of the Mu2e experiment.

JINR colleagues performed the tests of CsI matrix (3x3 units with dimensions 30x30x200 mm^3 each) with SiPM readout on the electron accelerator at Erevan Physics Institute (A.Alikhanyan National Laboratory). The energy of the electron accelerator was raised up to 70 MeV, so the available energy range now are 15-70 MeV. The test beam results is under processing. As well JINR scientists participated in the tests of CsI matrix and “module0” at Frascati electron accelerator with energy diapason 60-120 MeV [d4][d5][d7][d9]. The half of the “module 0” CsI crystals with dimensions 34x34x200 mm^3 , namely 25 units of ISMA manufactured were given to Mu2e collaboration as JINR in-kind contribution. The “module0” tests with our participation shown suitable energy resolution (5.3 % for 100 MeV incident electrons), perfect timing resolution (0.2-0.3 ns) and good linearity.[d1][d6][d12][d8][d10][d11][d13][d14][d16][d15][d17][d18][d19][d20] (4 FTE)

Our colleagues participated in the QA tests of the CsI crystals from initial procurement supply in CalTech Institute. They tested crystals for consistency with the calorimeter requirements including light yield (> 100 $N_{ph.el.}$/MeV) in 200 ns gate, longitudinal Response Uniformity (<5 %), fast to total component ratio, energy resolution. Part of the crystals from each party supplies were tested for radiation resistance from gamma and neutron sources. The suitable crystals were wrapped with Tyvek and prepared to the calorimeter assembly.[d18] (1 FTE)

JINR scientists assembled two cathode strip chambers and organized the cosmic muon test stand based on those chambers to test cosmic ray veto (CRV) modules of Mu2e veto system. Our scientists developed the procedure of the CRV module creation from the 4-layers scintillation strips and aluminum spacers. The length of such modules will extend from 2.5 up to 7 meters and weight of one module is several tons. The pilot modules were produced and tested at Virginia University. We developed and tested the procedure of filling the fiber holes with synthetic rubber (SKTN) to increase light yield of the modules to the 40-50 % [d21][d22]. The 7-meters modules is going to be filled by SKTN to provide effective operation for several years Mu2e data RUN. The samples of SKTN synthetic rubber as well as scintillator strips filled with such SKTN were tested on the JINR neutron facility for radiation hardness (up to neutron fluency $1.6x10^{15}$ neutron/ cm^2)[d23][d24]. They were shown very good resistance to neutron irradiation and could be used at veto system counters during physics RUN. Finally, our colleagues developed the procedure of the the CRV module assemble and participated in the assemble of 3 modules with 6-m long and 2 ton weight as well as assemble of 3 modules 3.2 meter length.(4 FTE)

Our colleague performed simulation of the Mu2e e.m. calorimeter in-situ calibration procedure. Our current studies show that the calorimeter can be calibrated using the data with the statistical accuracy better than 0.5%. Appropriate sample of DIO electrons can be obtained during the 10-20 minute long calibration run. (1 FTE)

Our colleagues participated in the design and tests of the calorimeter preamplifiers. The “module0” tests at Frascati electron beam have shown some preamplifiers nonlinearity for high energy deposition in crystals. The FEE boards were redesigned by our electronic engineer to provide good linearity and to satisfy the radiation hardness tests as well. The all of the calorimeter preamplifiers (3500 units) are going to be tested at special JINR created electronic stand. (2 FTE)

For 2-3 years with our colleges from Ioffe Institute (St. Petersburg) we are developing effective solar-blind photodetector, that can be applied for BaF2 fast component readout in Mu2e phase II. The main feature of this photodetector is to suppress low component of BaF2 scintillation with 320 nm peak luminosity and to register fast component with 230 nm peak and flash time less than 1 ns. Also our colleagues are performing RnD with thin multilayer filters produced by St.Petersburg groups trying to select fast BaF2 scintillation component using conventional SiPM [d25]. (3 FTE)

Further plans foresee:

- Finalization of the CRV modules production and tests (2020-2021) (2 FTE) JINR colleagues have established the production and testing of modules in the University of Virginia. We expect their further active participation in this work.
  As a result, all 86 of the system's veto modules will be manufactured, bench-tested on cosmic muons, and installed around the facility's data solenoid.
- Simulation and application of the calorimeter in-situ calibration (2021-2023) (1FTE). As a result, the method of rapid calibration of the e.m.calorimeter in special short RUNs with a half magnetic field in the data solenoid will be developed.
- Participation in the assemble and maintenance of the CRV and calorimeter (2021-2023) (3 FTE)
- RnD with solar blind photodiodes and filters for BaF_2 calorimeter (2021-2023) (2 FTE). This will help to create a workable in the solenoid magnetic field of 1 Tesla

and a price suitable photodetector for working with the fast scintillation component of BaF2 crystals. We emphasize that at the moment there are no suitable commercially available photodetectors for such applications.

- Neutron radiation tests of detector components (2021-2023) (1 FTE). All detector components as well as front end electronics must operate at design efficiency for a data RUN of at least 3 years.
- Data analysis (2023) (1 FTE). We plan to participate in the recovery of energies, angles and times of electron hit in the Mu2e calorimeter.

2. COMET experiment

COMET stands for COherent Muon to Electron Transition and the experiment seeks to measure the neutrinoless, coherent transition of a muon to an electron (μ−e conversion) in the field of an aluminium nucleus. The ideology of the experiment is the same (proposed by Vladimir Lobashev, along with physicist Rashid Djilkibaev in 1989) as for Mu2e Fermilab experiment and technical realization is very similar, including 8 GeV incident pulsed proton beam on target, superconducting solenoids with graduated magnetic fields, Al targets, straw tracker and crystal calorimeters.

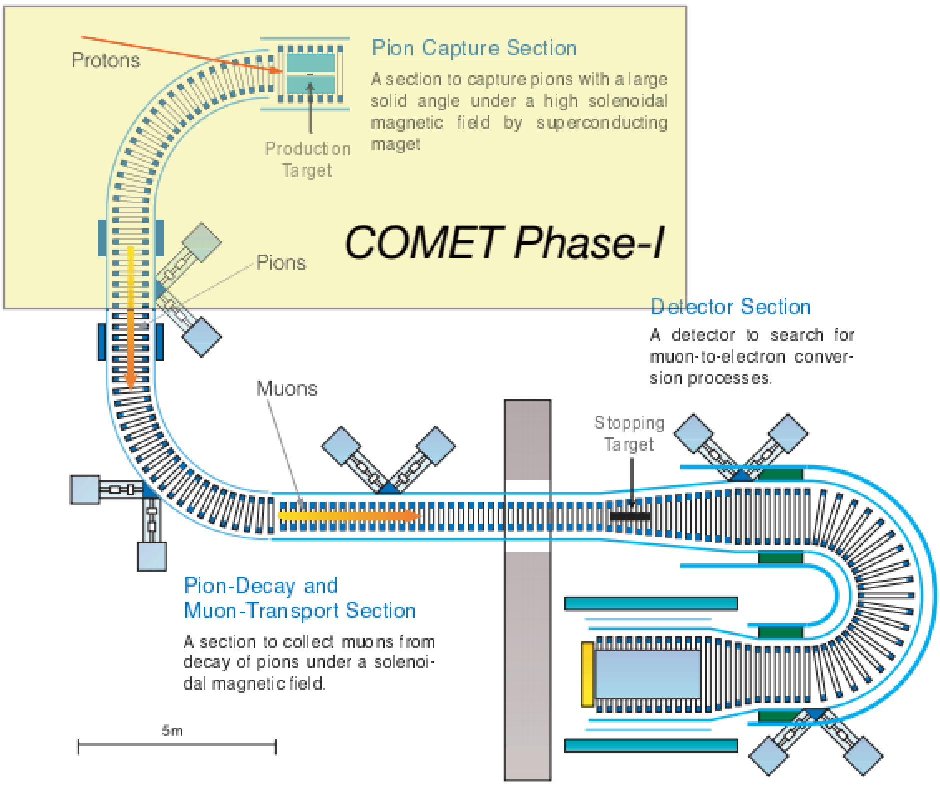

Fig. 2. Schematic layout of COMET (Phase-II) and COMET Phase-I (not to scale).

The COMET Phase-I aims at a signal sensitivity (SES) of 3.1×10^{-15} . A schematic layout of the COMET experiment is shown in Fig. 2. The experiment will be carried out in the Nuclear and Particle Physics Experimental Hall (NP Hall) at J-PARC using a bunched 8 GeV pulsed proton beam. The purpose of COMET Phase-I is two-fold. The first is to make **background measurements** for COMET Phase-II and the second is a **search for $\mu-e$ conversion** at an intermediate sensitivity. The COMET Phase-I serves several roles that are highly complementary to the Phase-II experiment. It provides a working experience of many of the components to be used in Phase-II and enables a direct measurement of backgrounds.

The apparatus begins with a pion-production target made of graphite located inside the pion capture solenoid, which provides a graded magnetic field to collect low-momentum pions by reflecting them backwards with respect to the incoming proton beam. The muon transport solenoid is a curved 90-degree magnet that, together with a set of dipole coils, serves as a transport and charge- and momentum-selection channel for $\pi^-\to\mu^-\nu$ decays. The muon transport solenoid delivers a high-intensity μ^- beam to the detector solenoid, which houses an aluminum stopping target and active detector elements, including a cylindrical drift chamber (CDC) for the $\mu^-\mathrm{N}\to e^-\mathrm{N}$ search and low-mass straw chambers and a fast LYSO crystal calorimeter for beam measurements. An active cosmic-ray veto system shadows the detector and stopping target regions outside the solenoid volume. Additional instrumentation monitors the proton and muon beams. Beam commissioning is expected to begin in 2020. The COMET Phase-I experiment will utilize about 3 kW of 8 GeV protons from the J-PARC Main Ring, delivered in pulses spaced by 1.17 μs, to first make important measurements of the muon yield and determine rates for various background processes before concentrating on a search for cLFV. After 150 days of operation the projected COMET Phase-I sensitivity is $R_{\mu e} < 7\times10^{-15}$ at 90% CL [16].

JINR contribution

The main contribution of JINR to COMET consists of participation in the production of two main detector systems – the electromagnetic calorimeter and the straw tracker, and includes variety of works on simulation.

For calorimeter we performed RnD of LYSO crystals to be used as e.m. calorimeter cells. The losses of the light yield along the crystal length, non-uniformity, energy resolution were experimentally measured. For this research LYSO crystals (20×20×120 mm^3), doped with 1.5% cerium of Saint-Gobain production, were used. In addition, a comparative estimate of the light yield for these crystals was obtained. The studies were performed by using a precision measuring setup, the results are published in [d26][d27]. It is established, that the energy resolution (FWHM) is on average equal to 8.9%, the coefficient of the non-uniformity is about 1.2 %/cm^{-1}.

The non-uniformity of the light yield along the crystal length affects the accuracy of the measurement of the energy released in the calorimeter. In order to reduce the non-uniformity of the light yield, it is necessary to ensure a uniform collection of photons along the crystal length of the crystal. To reduce these losses, special light-reflective wraps are used. For the development of techniques to improve the light collection we have investigated the light yield non-uniformity and energy resolution along the crystal length. It was obtained that improvement of light collection could be achieved by use TEFLON tape as the diffusion-type layer (inner layer) and ESR as mirror type layer (outer layer) [d32],[d30],[d31].

The purpose of certification of the crystals LYSO(Ce) is to obtain the individual properties of each crystal. The measured properties are the relative light output, the attenuation of light in the crystal, and the non-uniformity of the light output. For these measurements, a stand was created. The measurements were carried out using a radioactive source Na-22. For each crystal we get a passport describing its main characteristics. Currently, more than 100 crystals are measured.

Within the Phase-1 2700 full-size (1.2 m and 1.6 m length) straw tubes have been produced, after testing and checking according to quality standard all tubes were sent to Japan at KEK and from there to J-PARC. Due to the specific properties of Mylar and 20 μm wall thickness of straw tubes, long-term keeping requires constant monitoring and controlling of storage condition (quality control procedures must be carried out every 6 months). Experience has shown that in order to maintain normal physical storage conditions and ensure safe transportation from JINR to the KEK, the tubes must be under pressure. This also makes it possible to observe their behavior under similar conditions, like in a detector. For this, the tubes were prepared with the following conditions: initial gas pressure ~2.5 bar. The pressure in the tubes dropped about 0.7 bar during 2 years of storage. This is an excellent result for 20 μm wall thickness straw tubes. One of the causes of gas leakage is micro-shells between the wall of the straw and the endplugs, as well as the rubber ring between the endplugs and the gas blockers. In conclusion, the first measurements were done successfully, all safety conditions for long-term keeping are restored and straw tubes are ready for assembling in detector modules and for afterward tests.

Over the past years, a method of using ultrasonic welding technologies of straw production, which does not require multiple over-woven layers, has been developed by the JINR group for the NA62 experiment at CERN. In this method, a single layer is rolled and attached to itself in a straight line without using glue. Later by JINR-COMET group, this method and equipment were obtained in order to be improved and 2700 units of straw tubes were made for Phase-1 with thinner wall 20 μm and 9.8 mm in diameter. Many stress and long-term holding tests showed their reliability for using in vacuum conditions. According to the main requirements of COMET project in Phase-II must be used straw tubes with 12 μm thick walls and 5 mm in diameter. Thin walls of straw tubes is a crucial moment for tracker detector in order to reduce multiple scattering. In order to achieve the mentioned goals and make straws with the required parameters, the JINR-COMET group created a special laboratory to develop and produce unique straw tubes with new parameters using ultrasonic welding technology. The purpose of this laboratory is to manufacture and test straws with a wall thickness of 12 μm and a diameter of 5 mm. After configuring the welding machine and the first studies, the first welded pipes of straw with a length of 1400 mm, a thickness of 12 μm and a diameter of 5-10 mm were obtained. The quality of the seam was checked and showed good results for the preliminary tests. Straw tubes were pressurized on a working pressure 1 bar and after that pumped up with argon to 3 bar. The tubes held pressure without any leakage and visible damages. The other stress tests of 12 μm straw tubes and seam characteristics showed excellent results for quality and reliability. In the future, a more thorough study of the properties of straw tubes and the development of tests for quality control is planned. After the completion of all research work, the mass production of the COMET Phase-II experiment will begin. It is important that taking into account the success of JINR DLNP COMET group in R&D and production of thin-wall tubes with 5 mm diameters, and development of straw station design, the COMET collaboration supports the idea of JINR group to use an additional station with new tubes at Phase-1.

In order to ensure straw detector’s high coordinate accuracy, in addition to the precise positioning of the wire inside the tube and the tubes themselves in the detector’s modules the material from which straws are made is required to maintain its basic physical properties over time. As well as the material is required to be uniform throughout the length of the tube. The most important straw material’s physical properties are: the area of elastic deformation, the value of the elastic modulus, which characterizes the straw strength depends, the relaxation rate of tension. The Poisson's ratio allows determining the impact of pressure drop on the straw wall on its tension. These parameters largely influence the detector design's choice and the straw lifetime in the experiment. We defined working parameter space for our 9.8 mm straws. The results of measurements are being prepared for publication. An application for the patent for the invention on the bench with termostabilization system for measuring of properties of the straws is also being prepared.

Straw-ECAL combine test-beam experiment was conducted at ELPH (Research Center for Electron Photon Science, Tohoku University, Japan), on an electron (1.3 GeV) beam with the participation of members of the COMET collaboration from the DLNP. On the 105 MeV beam with spot size $\sigma_x \sim 6$ mm and $\sigma_y \sim 3$ mm were tested prototypes of an electromagnetic calorimeter and a straw tracker. A calorimeter prototype was composed of 16 modules of LYSO crystals. Each module consisted of 4 crystals, in total in the prototype were 64 crystals. The crystals used in the LYSO prototype (64 pieces) for test-beam, have been thoroughly investigated in DLNP JINR [d27] first, including light yield, light absorption, homogeneity etc. For beam test was prepared full-size straw tracker prototype, using straw tubes developed and produced by JINR group. Straw tubes showed closed to 100% efficiency for the $Ar:C_2H_6$ (50:50) gas mixture starting 1800 V applied HV. A spatial resolution of 143.2 μm for the HV of 1900 V is obtained. This value includes the uncertainties arising from the precision of track reconstruction, and if this is taken into account the true spatial resolution is estimated to be 119.3 μm. For 105 MeV electron energy resolution for the calorimeter prototype varies from 3.8% to 4.4%, depending on the beam hit, the position resolution is $\sigma_R = 5.8$ mm.

Development of the straw tracker and calorimeter systems required a lot of simulation work. The corresponding results are presented in the Technical Design Report for Phase-I of COMET [15]. In particular, the values of efficiency and space resolution in different conditions: for the tubes of different diameters, wall thicknesses and gaps between the tubes, for the straw tracker have been established. Similarly, the calorimeter simulation has been done for two types of crystals, GSO and LYSO using the real optical parameters. Among others, simulation of light outputs and light collection with different reflecting materials also has been performed.

Further plans foresee:

- Finalization assembling, testing, installation, cosmic test and calibration of the straw detector for Phase-I **2021 -2022**
- R&D program for production of the straw tubes of 12 μm wall thickness and 5 mm diameter for Phase-I (about 1000 pcs), production of prototypes and their measurement on beam **2021 -2022**
- Measuring of all mechanical properties and development of standards for quality control of manufactured of the 5 mm brand-new straw tubes **2021 -2022**
- Production of a full-scale straw station with new tubes (12 μm, 5 mm) **2021 -2022**
- Preparation for mass-production and testing of straw tubes for Phase-II **2023**
- Test (certification) of the crystals in JINR to be used in the calorimeter, **2021-2022**
- Development of a crystal calibration method for a COMET calorimeter, given the features of the experiment: the presence of a magnetic field and high resolution calorimeter**, 2021 - 2023**

- Optimization of crystal calibration methods**,** testing and calibration of crystals **2021 - 202023**
- Participation in the calorimeter designing, assembling and cosmic test, **2021-2022**
- Participation in the beam tests of the detector components for Phase II, **2021 - 2023**

MEG-II experiment

The MEG II experiment [14][d41] is shown in Fig.3. The main features are an e+ spectrometer formed by a new cylindrical drift chamber[d43],[d44],[d45] plus precision pixelated timing counters, located inside a superconducting solenoid with a graded magnetic field along the beam axis, and a detector, located outside the solenoid, made up of a homogeneous volume of 900 liters of liquid xenon readout in the central region by silicon photomultipliers and in the forward and background region by photomultiplier tubes. The finer granularity of the silicon photomultipliers provides improved angular and energy resolution. Additional systems are used to further reduce RMD background, and to monitor the beam quality and stopping target in situ. The detector construction is complete and commissioning has begun. The upgraded detector is expected to provide resolutions roughly a factor of two better than MEG, thus allowing MEG II to utilize the full muon beam intensity available at PSI, $I_{\mu} \sim 10^{8}$ stop-μ+/s, to achieve a factor of ten improvement in expected sensitivity.

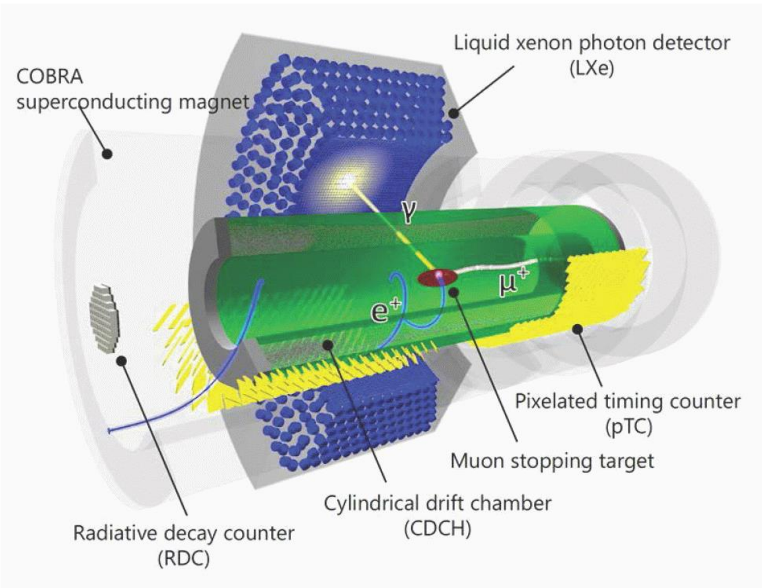

Fig.3 Schematic of the MEG II experiment.

JINR contribution

Development and support of event 3D visualization software. We suggested MEGII collaboration to develop Event Display web application based on new technology using of WebGL library. The main goal of the project is development Web based server and client application to visualize 3D interactive models of all sensors of MEGII detector connected to event data stream in online and offline modes for presentation and supervisory tasks without additional software on client side. Client part of the Event Display should use only standard methods which are available in modern Web browsers from different vendors supporting JavaScript dialects starting from ECMAScript 2015 and newest. Clients should have possibilities to use mobile devices as well. Working demo version of the Event Display was successfully presented at the MEG2 collaboration meeting July 2019 and available at **g2mu.jinr.ru/three**.

DLNP JINR computing cluster was configured to work with MEG-II software. Cluster includes 800 CPU's for batch jobs processing. Data storage is located on the local disk pools and disks provided by JINR AFS system. Cluster works under Linux operating system. Servers run 64-bit version of CentOS7. Cluster has installed a lot of Linux programs and libraries, including standard development tools like C/C++, FORTRAN (GNU, Intel), Octave, Perl, Python etc. For MEG II software 29TB local disk pool is assigned for MEG II simulation, data processing and physics analysis. MySQL server is working. Special versions of packages ROOT, GenFit and Geant4 (modified to use in the MEG II software enviroment), MeG II libraries and database are installed. Full chain of MEG II simulation and analysis programs was tested successfully. Our cluster is certified for work in MEG II collaboration. Members of LNP MEG II group started to study the drift chamber simulation and pattern recognition software. MEG II collaboration participants run their jobs on LNP JINR cluster.

A modification of the standard package Geant4, which allowed to correctly describe the energy loss in the calorimeter is proposed. We together with the data Center of photonuclear experiments (Varlamov V. V., etc.) of MSU are going to include the calculated cross sections of photonuclear processes for Xe in the MEG-II modeling package.

For the MEG II drift chamber we developed a new method of measurement of wire tension inside closed volume of the positron tracker for control of the detector performance. (A. O. Kolesnikov, V. L. Malyshev, N. P. Kravchuk, A. I. Rudenko) .

An improved design of the cylindrical drift chamber (CDCH) has been developed and presented to the collaboration. Special attention is paid to the analysis of cells, which form an electric field in the CDCH. It has been shown that number of factors: gravitation, electrostatic and errors in the manufacturing - make a significant impact on uniformity of electric field, i.e. on coordinate accuracy. The cell's form suggested doesn't change an electric field in the cell in principle, but allows to reduce a quantity of material and control mechanical tension of wires. (A. O. Kolesnikov, N. P. Kravchuk, K. K. Limarev).

We are developing and supporting of user-friendly web interface software for control and setup of multiple parameters of the WaveDREAM boards in the WaveDAQ integrated trigger and data acquisition system. The software based on JavaScript Custom Page technology for MIDAS is a practical and robust tool to manage thousands of WaveDAQ electronics channels. (N.V. Khomutov).

Further plans foresee

- Maintenance of the cylindrical drift chamber in the MEG-II experiment (2021-2023) (2 FTE)
- Developing, finalizing and supporting of the event visualization display (2021-2023) (1 FTE)
- Developing and supporting of the MEG II DAQ (1 FTE) (2021-2023)
- Ensure the operation of the JINR computer cluster for simulation and data analysis. Increasing the computer cluster data storage and power by necessity. (1 FTE) (2021-2023)
- Participation in the drift chamber simulation, track reconstruction procedures, precise energy reconstruction in Xe calorimeter and further in data analysis (2 FTE) (2021-2023).

Estimation of human resources

Mu2e JINR group members

Name	FTE	Positon	Work (apart common duties like shifts)
A.M.Artikov	0.6	Head of sector	CRV creation and maintenance
N.V.Atanov	0.9	Junior researcher	Calorimeter, front end electronics, RnD Mu2e-II
O.S.Atanova	0.4	Engineer	front end electronics, RnD Mu2e-II
V.Yu. Baranov	0.5	Junior researcher	Calorimeter, RnD Mu2e-II
J.A. Budagov	0.4	Chief researcher	CRV, Calorimeter, RnD Mu2e-II
D. Chokheli	0.6	Senior scientist	CRV creation and maintenance
Yu.I. Davydov	0.5	Head of department	Calorimeter, RnD Mu2e-II
D.L. Demin	0.3	Head of sector	RnD Mu2e-II
V.V. Glagolev	0.6	DLNP Deputy director	CRV, Calorimeter, RnD Mu2e-II
Yu.N. Kharzheev	0.4	Senior scientist	CRV, RnD Mu2e-II
V.I. Kolomoets	0.3	Senior engineer	CRV, calorimeter
S.M. Kolomoets	0.3	Senior engineer	CRV, calorimeter
A.V. Sazonova	0.3	Engineer	CRV
A.N. Shalyugin	0.3	Senior engineer	Calorimeter, RnD Mu2e-II
A.V.Simonenko	0.6	scientist	CRV creation and maintenance
I.A. Suslov	0.6	Senior scientist	Calorimeter calibration simulation
V.V. Tereschenko	0.4	Head of group	Calorimeter electronics, RnD Mu2e-II
S.V. Tereschenko	0.3	Engineer	Calorimeter electronics, RnD Mu2e-II
Z. Usubov	0.6	Senior scientist	CRV and calorimeter simulation
I.I. Vasilyev	0.5	Junior researcher	Calorimeter RnD and tests
Total FTE	**9.4**		

COMET JINR group members

Name	FTE	Positon	Work (apart common duties like shifts)
G. Adamov	0.7	Junior researcher PhD student	Software tools development, analysis
D. Aznabayev	0.2	Junior researcher PhD student	Theoretical issues, physics analysis
D. Baygarashev	0.2	Junior researcher PhD student	Data quality control, calibration, physics analysis
V.N. Duginov	0.5	Deputy head of department	Calorimeter development, analysis
T.L. Enik	0.2	Head of sector	Hardware development and support
K.I. Gritsai	0.2	Senior scientist	Software tools development
I.L. Evtoukhovitch	0.7	Senior engineer	Hardware support
P.G. Evtoukhovitch	1.0	Senior scientist	Hardware development and support
V.A. Kalinnikov	0.9	Leading scientist	Calorimeter development, MC, analysis
E.S. Kaneva	1.0	Engineer	MC development, analysis

X. Khubashvili	0.7	Engineer	Hardware support
A. Khvedelidze	0.3	Leading scientist	Theoretical issues, models development
A. Kobey	0.5	Master student	Calorimeter development, MC, analysis
G.A. Kozlov	0.2	Leading scientist	Theoretical issues, models development
M.D. Kravchenko	1.0	Junior researcher PhD student	Hardware development, data quality control, analysis
A.S. Moiseenko	1.0	Scientist	Hardware development and support
A. Issadykov	0.2	Senior scientist	Theoretical issues, physics analysis
A.V. Pavlov	1.0	Junior researcher PhD student	MC, Data quality control, physics analysis
B.M. Sabirov	1.0	Scientist	Hardware development and support
A.G. Samartsev	0.2	Senior engineer	Hardware development, detector design
Z. Tsamalaidze	0.7	Head of sector	Project leader
N. Tsverava	1.0	Junior researcher PhD student	Hardware development, calibration, analysis
E.P. Velicheva	1.0	Senior scientist	Calorimeter development, MC, analysis
A.D. Volkov	1.0	Scientist	Hardware development
Total FTE	**15.4**		

MEG-II JINR group members

Name	FTE	Positon	Work (apart common duties like shifts)
V.A. Baranov	0.6	Senior scientist	Drift chamber simulation, data analysis
N.V. Khomutov	1.0	Scientist	DAQ software development
A.O. Kolesnikov	0.4	Senior engineer	Drift chamber upgrade and maintenance
N.P. Kravchuk	0.8	Senior scientist	Drift chamber upgrade and maintenance
V.A. Krylov	0.8	Scientist	Display event monitor
N.A. Kuchinsky	0.6	Senior scientist	Drift chamber upgrade and maintenance
V.L. Malyshev	0.4	Scientist	Drift chamber upgrade and maintenance
K.K. Limarev	0.4	Engineer	Drift chamber simulation, data analysis
A.M. Rozhdestvensky	0.6	Senior scientist	DLNP MEG-II computer cluster support, data analysis
Yu.P. Ivanov	0.3	Senior scientist	DLNP MEG-II computer cluster support
A.V. Simonenko	0.2	scientist	simulation
I.V. Titkova	0.3	DLNP scientific Secretary	Drift chamber simulation
Total FTE	**6.4**		

SWOT Analysis

The JINR scientists fruitfully participated in the Mu2e, Comet and MEG-II experiments for several years. The history of research in muon physics comes from the DLNP early times. The strength of the Project is to participation on the front end of particle physics and New physics searches in the CLFV sector which is widely recognized by world community and is complimentary to new models tests at LHC. In practice, this Project brings together JINR employees 'participation in the world's main experiments to search for CLFV processes with muons with the exception of the mu-3e experiment in PSI, which lags behind on the energy scale in the search for new physics compared to Mu2e and COMET. JINR colleagues have achieved great success in preparing for the operation of the respective detectors. In particular, we have proposed and tested a way to increase the light collection from long 5-7 m veto counters. We are conducting a promising RnD on the application of a new type of photodetectors to work with the fast component of BaF_2 crystals. Employees of DLNP created a stand and conducted the first tests on welding of ultrathin 12 microns straw tubes. Our colleagues are developing a cross platform display event monitor

The relatively weakness is in the current situation of interaction with American colleagues which could have impact on the Mu2e cooperation. However, by combining participation in Mu2e-Comet similar experiments, we will be able to redirect the efforts of our experts on the veto system to the Comet experiment, which is very welcome by Japanese colleagues.

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Conference talks:

1. Yu. Kharzheev, “Radiation Hardness of scintillation detectors based on organic plastic scintillators and optical fibers”, International Conference “New trends in High-Energy Physics” Monternegro, Budva 24-30 September 2018
2. Yu.I.Davydov et al., “Tests of 3x3 undoped CsI matrix with an extremely low intensity electron beam”, International Conference “New trends in High-Energy Physics” Monternegro, Budva 24-30 September 2018
3. A.M. Artikov, V. Baranov, J.A. Budagov, A.N. Chivanov, Yu.I. Davydov, E.N. Eliseev, E.A. Garibin, V.V. Glagolev, A.V. Mihailov, V.V. Terechschenko, I.I.Vasilyev “Suppression of a slow component of a BaF2 crystal luminescence with a thin multilayer filter” CALOR 2018 - 18th International Conference on Calorimetry in Particle Physics, Eugene, Oregon, USA, May 21-25, 2018
4. N. V. Khomutov, Using the cathode surface of straw tube for measuring the track coordinate along the wire and increasing rate capability, New Trends in High-Energy Physics. Budva, Becici, Montenegro, 02 October - 08 October, 2016.
5. N. P. Kravchuk, Tracker prototype on a base of cathode straw, Fifth International Conference ESMART 2016 "Engineering of Scintillation Materials a 01-nd Radiation Technologies", September 26-30, 2016, Minsk, Belarus.
6. V.A. Krylov. Development of web interactive 3D environment for event display in muon g-2 (Fermilab) and MEG-2 (PSI) experiments. NEC-2019, Budva, Becici, Montenegro, 30 September - 04 October, 2019.
7. N. A. Kuchinskiy, The MEG Experiment. Search For Physics Beyond The Standard Model, XIV-th International School-Conference "Actual Problems of Microworld Physics", 12-August, 24, 2018, Grodno, Belarus
8. N. A. Kuchinskiy, N. P.Kravchuk. Search For Physics Beyond The Standard Model, XIII-th International School-Conference "Actual Problems of Microworld Physics", 27 July-7 August, 2017, Gomel, Belarus.
9. Limarev K. K., A note of a design of CDCH, 23-th Conference AYSS-2019, Alushta.
10. A. Artikov, S. Boi, J. Budagov, D. Chokheli, Y. Davydov, E. C. Dukes, R. Ehrlich, V. Glagolev, R. C. Group, Y. Kharzheev, Y. Oksuzian, A. Simonenko, I. Vasilyev “Mass Production and Quality Tests of a High-Efficiency Cosmic Ray Veto Detector for the Mu2e Experiment”, IEEE Nuclear Science Symposium, 26 October – 2 November 2019, Manchester, UK

Appendix 3

Form No. 26

Schedule proposal and resources required for the implementation of the Project

Search for new physics in the lepton sector

Expenditures, resources, financing sources			Costs (k$) Resource requirements	Proposals of the Laboratory on the distribution of finances and resources		
				2021	2022	2023
Expenditures		Computers for RnD and MC Electronic devices for stands	130 k$ 270 k$	50 90	40 90	40 90
		Construction/repair of premises				
		Materials	270 k$	90	90	90
Required resources	Standard hour	Resources of – Laboratory design bureau; – JINR Experimental Workshop; – Laboratory experimental facilities division; – electron accelerator; reactor – computer. Operating costs.	 1250 h 1200 h 840 h	 450 h 500 h 280 h	 450 h 500 h 280 h	 350 h 200 h 280 h
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources.	1258 k$	426	416	416
	External resources	-FNAL and UVA visits support -Grant of the Plenipotentiary of Georgia - Program of the JINR-Belarus Cooperation. - Grant of the Plenipotentiary of Kazakhstan - Travel support from PSI	45 k$ 30 k$ 45 k$ 30 k$ 15 k$	15 10 15 10 5	15 10 15 10 5	15 10 15 10 5

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Appendix 4

Form No. 29

Estimated expenditures for the Project

Search for new physics in the lepton sector

(full title of Project)

	Expenditure items	Full cost	2021	2022	2023
	Direct expenses for the Project				
1.	Accelerator, reactor	840 h	280 h	280 h	280 h
2.	Computers	h			
3.	Computer connection	30 k$	10	10	10
4.	Design bureau	1250 h	450 h	450 h	350 h
5.	Experimental Workshop	1200 h	500 h	500 h	200 h
6.	Materials	270 k$	90	90	90
7.	Equipment	400 k$	140	130	130
8.	Construction/repair of premises	k$			
9.	Payments for agreement-based research (operation fee)	60 k$	20	20	20
10.	Travel allowance, including:				
	a) non-rouble zone countries	465 k$	155	155	155
	b) rouble zone countries	33 k$	11	11	11
	c) protocol-based				
	Total direct expenses	1258 k$	426	416	416

PROJECT LEADER

LABORATORY DIRECTOR

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concise justification of the requested expenditures

Below are tables that divide the requested resources into three experiments.

For Mu2e experiment :

- Computers: Personal computers and servers for software development and simulation; for DLNP experimental stands DAQ and data analysis.
- Electronic devices: VME modules, trigger logic, power supplies for PMT and SiPM's, SiPM's for trigger counters, crystals, oscilloscope's, equipment of test stands for work with cosmic, radioactive sources and electron accelerator.
- Materials : AlGaN photocathodes, microchannel plates, BaF2 crystals, printing plastic for the 3D, small tools, modular profile.

For COMET experiment :

- Computers: Personal computers and servers for software development and simulation; for DLNP experimental stands DAQ and data analysis.
- Electronic devices: equipment for straw tube testing stand, VME modules, power supplies, optical sensors, pressure sensors, equipment of test stands for work with cosmic, radioactive sources and electron accelerator.
- Materials : Mylar for straw tubes production, scintillator plates, printing plastic for the 3D, argon.

For MEG-II experiment :

- Computers: DLNP computing cluster and disk storage upgrade. Personal computers, servers and computer components for software development, simulation, experimental data processing and physics analysis.
- Electronic devices: VME and WaveDREAM modules for DAQ R&D and simulation.
- Materials for the drift chamber R&D : aluminium wire, solder, conducting glue, epoxy, gas mixtures, chemicals, 3D printing plastic, small tools, modular profile.

Appendix 3.1

Form No. 26

Schedule proposal and resources required for the implementation of the experiment

Mu2e

<table>
<tr><td colspan="3" rowspan="2">Expenditures, resources, financing sources</td><td rowspan="2">Costs (k$)
Resource requirements</td><td colspan="3">Proposals of the Laboratory on the distribution of finances and resources</td></tr>
<tr><td>2021</td><td>2022</td><td>2023</td></tr>
<tr><td colspan="2" rowspan="3">Expenditures</td><td>Computers for RnD and MC
Electronic devices for stands</td><td>30
120</td><td>10
40</td><td>10
40</td><td>10
40</td></tr>
<tr><td>Construction/repair of premises</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Materials</td><td>60</td><td>20</td><td>20</td><td>20</td></tr>
<tr><td>Required resources</td><td>Standard hour</td><td>Resources of
– Laboratory design bureau;
– JINR Experimental Workshop;
– Laboratory experimental facilities division;
– electron accelerator; reactor
– computer.
Operating costs.</td><td>300 h

360 h</td><td>100

120</td><td>100

120</td><td>100

120</td></tr>
<tr><td rowspan="2">Financing sources</td><td>Budgetary resources</td><td>Budget expenditures including foreign-currency resources.</td><td>387</td><td>129</td><td>129</td><td>129</td></tr>
<tr><td>External resources</td><td>FNAL and UVA visits support</td><td>45</td><td>15</td><td>15</td><td>15</td></tr>
</table>

PROJECT LEADER

Appendix 4.1

Form No. 29

Estimated expenditures for the experiment ______________________Mu2e____________________

(full title of Project)

	Expenditure items	Full cost	2021	2022	2023
	Direct expenses for the Project				
1.	Accelerator, reactor	360 h	120	120	120
2.	Computers	h			
3.	Computer connection	15 k$	5	5	5
4.	Design bureau	300 h	100 h	100 h	100 h
5.	Experimental Workshop				
6.	Materials	60 k$	20	20	20
7.	Equipment	150 k$	50	50	50
8.	Construction/repair of premises	k$			
9.	Payments for agreement-based research (operation fee)	k$			
10.	Travel allowance, including:				
	a) non-rouble zone countries	150 k$	50	50	50
	b) rouble zone countries	12	4	4	4
	c) protocol-based				
	Total direct expenses	387	129	129	129

PROJECT LEADER

LABORATORY DIRECTOR

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Appendix 3.2

Form No. 26

Schedule proposal and resources required for the implementation of the experiment

COMET

Expenditures, resources, financing sources			Costs (k$) Resource requirements	Proposals of the Laboratory on the distribution of finances and resources		
				2021	2022	2023
Expenditures		Computers Electronic devices	30 120	10 40	10 40	10 40
		Construction/repair of premises				
		Materials	180	60	60	60
Required resources	Standard hour	Resources of – Laboratory design bureau; – JINR Experimental Workshop; – Laboratory experimental facilities division; – accelerator; – computer. Operating costs.	800 h 1200 h	300 500	300 500	200 200
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources.	660	220	220	220
	External resources	Grant of the Plenipotentiary of Georgia	30	10	10	10
		Program of the JINR-Belarus Cooperation.	15	5	5	5
		Grant of the Plenipotentiary of Kazakhstan	30	10	10	10

PROJECT LEADER

Appendix 4.2

Form No. 29

Estimated expenditures for the experiment Comet

(full title of Project)

	Expenditure items	Full cost	2021	2022	2023
	Direct expenses for the Project				
1.	Accelerator, reactor	480 h	160	160	160
2.	Computers	h			
3.	Computer connection	k$			
4.	Design bureau	800 h	300 h	300 h	200 h
5.	Experimental Workshop	1200 h	500 h	500 h	200 h
6.	Materials	180 k$	60	60	60
7.	Equipment	150 k$	50	50	50
8.	Construction/repair of premises	k$			
9.	Payments for agreement-based research (operation fee)	60 k$	20	20	20
10.	Travel allowance, including:	k$			
	a) non-rouble zone countries	255	85	85	85
	b) rouble zone countries	15	5	5	5
	c) protocol-based				
	Total direct expenses	660	220	220	220

PROJECT LEADER

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Appendix 3.3

Form No. 26

Schedule proposal and resources required for the implementation of the experiment

MEG-II

<table>
<tr><td colspan="3" rowspan="2">Expenditures, resources, financing sources</td><td rowspan="2">Costs (k$)
Resource requirements</td><td colspan="3">Proposals of the Laboratory on the distribution of finances and resources</td></tr>
<tr><td>2021</td><td>2022</td><td>2023</td></tr>
<tr><td colspan="2" rowspan="3">Expenditures</td><td>Computers
Electronic devices</td><td>70
30</td><td>30
10</td><td>20
10</td><td>20
10</td></tr>
<tr><td>Construction/repair of premises</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Materials</td><td>30</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Required resources</td><td>Standard hour</td><td>Resources of
– Laboratory design bureau;
– JINR Experimental Workshop;
– Laboratory experimental facilities division;
– accelerator;
– computer.
Operating costs.</td><td>150 h</td><td>50</td><td>50</td><td>50</td></tr>
<tr><td rowspan="3">Financing sources</td><td>Budgetary resources</td><td>Budget expenditures including foreign-currency resources.</td><td>211 k$</td><td>77</td><td>67</td><td>67</td></tr>
<tr><td rowspan="2">External resources</td><td>Program of the JINR-Belarus Cooperation.</td><td>30 k$</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Travel support from PSI</td><td>15 k$</td><td>5</td><td>5</td><td>5</td></tr>
</table>

PROJECT LEADER

Appendix 4.3

Form No. 29

Estimated expenditures for the experiment ____________________MEG-II____________

(full title of Project)

Expenditure items	Full cost	2021	2022	2023
Direct expenses for the Project				
1. Accelerator, reactor	h			
2. Computers	h			
3. Computer connection	15 k$	5	5	5
4. Design bureau	150 h	50 h	50 h	50 h
5. Experimental Workshop	h			
6. Materials	30 k$	10	10	10
7. Equipment	100 k$	40	30	30
8. Construction/repair of premises	k$			
9. Travel allowance, including:				
a) non-rouble zone countries	60 k$	20	20	20
b) rouble zone countries	6	2	2	2
c) protocol-based				
Total direct expenses	211 k$	77	67	67

PROJECT LEADER

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