QUESTIONNAIRE (Mu2e and *g-2*)

1. Goals of the experiment:

1a. Give a short description of the goals of the experiment - limited to ½ page.

The muon anomalous magnetic moment a_μ can be measured and computed to high precision. The comparison between experiment and the SM therefore provides a sensitive search for New Physics (NP). At present, both measurement and theory have sub-part-per-million (ppm) uncertainties, and the ``***g-2* test**'' is being used to constrain SM extensions. The difference between experiment and theory, $\Delta a_\mu(Expt\text{-}SM) = (255 \pm 80) \times 10^{-11}$ $(3{,}2\ \sigma$, is a highly cited result and a possible harbinger of new TeV-scale physics.

Potential explanations of the deviation include: supersymmetry, lepton substructure, dark matter loop etc., all well motivated by theory and consistent with other experimental constraints. Fermilab experiment has a plan to reduce the experimental uncertainty by a factor of 4 or more. A precise *g-2* test, no matter where the final value lands, will sharply discriminate among models and will enter as one of the central observables in a global analysis of any SM extensions.

The **Mu2e** experiment at Fermilab is a dedicated search for the CLFV process $\mu^- N \rightarrow e^- N$, which is the coherent conversion of a muon into an electron in the vicinity of a nucleus. Once neutrinos masses are included, the process is allowed but effectively still absent since the rate is proportional to $(\Delta m^2_{ij}/M^2_W)^2$, where Δm^2_{ij} is the mass difference squared between i-th and j-th neutrino mass eigenstates, and M_W is the mass of the W-boson. The predicted rates for the $\mu^- N \rightarrow e^- N$ and $\mu^+ \rightarrow e^+ \gamma$ CLFV processes are less than 10^{-50} each. This makes this process a very theoretically clean place to search for NP effects. In many NP models that include a description of neutrino mass, the rates for these processes are enormously enhanced so that they occur at a level to which Mu2e experiment will have sensitivity.

1b. Explain what the project adds to the international scenario: limited to ½ page.

Fermilab muon *g-2* experiment has a plan to reduce the experimental uncertainty by a factor of 4 or more. This reduction will lead to a more definitive result - $\Delta a_\mu > 5\sigma$ "discovery-level" deviation from the SM - if the central value remains unchanged. A precise *g-2* test, no matter where the final value lands, will sharply discriminate among models and will enter as one of the central observables in a global analysis of any SM extensions.

There are a variety of CLFV experiments with sensitivities approaching theoretically interesting regions. These include CLFV tau lepton, muon, kaon, and b-meson decays. Among these the $\mu^- N \rightarrow e^- N$ process has sensitivity to the broadest array of NP models. Like the $\mu^+ \rightarrow e^+ \gamma$, $\mu^+ \rightarrow e^+ e^- e^+$, or $\tau^+ \rightarrow \mu^+ \gamma$ processes, $\mu^- N \rightarrow e^- N$ is sensitive to NP contributions via loops, such as those expected in Supersymmetry via slepton mixing, induced in seasaw models of Heavy Neutrinos, and present in two Higgs doublet models. In addition, the $\mu^- N \rightarrow e^- N$ process is also sensitive to NP contributions via contact interactions, such as those expected in Compositeness, Leptoquark, and GUT models with additional gauge bosons and/or anomalous couplings. The above models predict rates as large as 10^{-15} in regions of phase space that overlap with LHC discovery sensitivities.

2. Contributions of the JINR group:

2a. Give an itemized list of the specific contributions of the JINR group in hardware (including use of JINR computing resources for the project), software development and physics analyses - limited to 1 page.

I. Mu2e experiment contribution :
   a. Cosmic Ray Veto (CRV) system :
      i. R&D for scintillation counters light yield increasing. Filling the fiber holes with synthetic low molecular weight rubber (SKTN-MED) gives up to 50 % light yield

gain compare to the drain fiber holes. The technique of injection of viscous filler into the hole with fibers has been worked out. This is especially important and is going to be done for long CRV modules (up to 7 meters long) with one end SiPM readout. There is a probability that Mu2e collaboration in 2019 will make a decision about filling all CRV modules with CKTN. Radiation tests of the filled counter samples as well as SKTN-MED samples alone were performed at the JINR IBR-2 reactor. The tests showed the possibility to use SKTN-MED in the neutron fluence up to $1.6x10^{16}$ per cm^2, which is 10 times higher than expected in the Mu2e experiment over 3 years.

   ii. Participation in the CRV counters tests at the Fermilab proton beam.
   iii. The development of the CRV module test bench included the manufacture of cathode strip chambers (4 PCs.), the tests of chambers using ~~a~~ radioactive sources and cosmic muons at Virginia University.
   iv. Creation of the methodic of 4-layer CRV modules assembly and gluing at Virginia University. The stages consisted of gluing strips in pairs (dicounter), trimming of dicounter in length, equipping them with optical fibers, attaching adapters to dicounters, the final processing of the surface of the adapter with glued optical fibers with a diamond cutter, testing dicounter on established stand with a radioactive source. Finally, we assembled prepared dicounters in layers (4 layers) and bonded them to aluminum plates (5 PCs.).To date, several prototypes of short (90 cm) and long (4 m) modules have been created.

b. Electromagnetic calorimeter
   i. Simulation of the electromagnetic calorimeter calibration in situ using the half of the nominal magnetic field in the data solenoid.
   ii. RnD with LYSO crystals as elements of the calorimeter. Radioactive sources and cosmic muon tests. Testing the longitudinal uniformity of the crystals. Testing timing resolution of the LYSO calorimeter prototype. Participation in the test beams at Frascati electron accelerator.
   iii. R&D with CsI crystals. Tests of single crystals and matrices on the sources and electron accelerators. Testing timing and energy resolution of the CsI calorimeter prototype. Several tests at Frascati and Yerevan electron accelerator have shown good linearity and energy resolution.
   iv. Participation in Module0 CsI calorimeter testing in Frascati.
   v. Participation in the calorimeter preamplifiers design and tests at Frascati.
   vi. Participation in the gamma radiation tests of the FEE for electromagnetic calorimeter in Casaccia ENEA.
   vii. Preparation of ~~the~~ stand at Dubna for tests of the whole set of preamplifiers.
   viii. R&D with BaF2 crystals, which are planned to be used in the second stage of Mu2e experiment with 10 times higher beam intensity. Ongoing tests of the pilot photomultiplier with AlxGa(1-x)N photocathodes and micro channel plates. The tricky part is that only fast UV component of the BaF2 crystal luminescence (220-260 nm) should be registered and the slow component with wave length above 260 nm should be suppressed.

II. Muon *g-2* experiment contribution :

a. The alarm system for the experiment (based on MIDAS DAQ framework) was developed and successfully used during the data taking run. Also the web-interface software tools for experiment DAQ control based on JavaScript Custom Page technology for MIDAS were developed and used.
b. A cross-platform graphical Event Display application was developed to visualize online experimental events based on Geant4 geometry. The development time of the program significantly shortened thanks to the use of the programming language Python v2.7 and graphics libraries VTK, Matplotlib and Numpy. The interface between Geant4, Paraview and the VTK library is the well-known HepRep format for the presentation of graphics data.
c. R&D works for a tracker prototype based on cathode straw tubes.

2b. Give a list of the responsibilities of JINR group members within the management structure of the collaboration, if any, giving the name of the JINR member, the managerial role and the appointment period.

Vladimir Glagolev is the Mu2e experiment Institutional Board member .

3. Plans

Give a short description limited to ½ page of the JINR group plans (in data taking, analysis, detector R&D, upgrade activities…) till the end of the currently approved project.

Mu2e experiment :

- **I.** Participation in the production of the CRV modules at Virginia University.
- **II.** Creation the system for parallel filling of the fiber holes with SKTN for several discounters simultaneously.
- **III.** Filling the discounters for all long CRV modules (about 7 meters) and probably for whole set of CRV modules if collaboration will decide it in 2019. Dubna colleagues are responsible for this task.
- **IV.** Performing tests of the ready CRV modules with radioactive sources and muon stand.
- **V.** Participation in the CsI crystals QA (quality assurance) tests at CalTech before e.m. calorimeter assembly.
- **VI.** Creation test bench for tests of the Mu2e e.m. calorimeter preamplifiers
- **VII.** Performing tests of all e.m. calorimeter preamplifiers at Dubna.
- **VIII.** Performing neutron radiation hardness tests of preamplifiers at Dubna IBR-2.
- **IX.** Evaluating the performance of Tracker panels at the University of Minnesota. QA and QC of Tracker panels as they are produced (testing for leaks, holding high voltage, etc.)
- **X.** Continue R&D with BaF2 crystals which are planning to be used in the second stage of the Mu2e experiment.
- **XI.** Continue simulation of the e.m. calorimeter calibration.
- **XII.** Participation in the Mu2e detector assembly, tests and commissioning.

Muon *g-2* experiment :

- I. Development of new custom JavaScript web pages for the MIDAS ODB control.
- II. Participation in tuning and running of the full DAQ system. Expert support of the MIDAS software during physics runs 2018-2020.
- III. Support and further development of the Event Display application.
- IV. Possible participation in the run shifts during physics runs 2019-2020.
- V. Possible participation in the analysis of the experimental data.

4. Publications: *List the papers published in 2016, 2017 and 2018 in the refereed literature (no conference proceedings) in which the JINR group had a major contribution (e.g. author of the analysis, promoter of the experiment, corresponding author, realization of a key equipment etc.). Give title of paper, reference and describe in 1-2 sentences the JINR contribution. Mention the total number of papers published by the project in the same time period.*

1. A. Artikov,V. Baranov, Ju. Budagov, D. Chokheli, Yu. Davydov, V. Glagolev, Yu. Kharzheev,V. Kolomoetz, A. Shalugin, A. Simonenko and V. Tereshchenko, Optimization of light yield by injecting an optical filler into the co-extruded hole of the plastic scintillation bar //2016 JINST 11 T05003
2. A. M. Artikov, V. Yu. Baranov, J. A. Budagov, V. V. Glagolev, Yu. I. Davydov, V. I. Kolomoets, A. V. Simonenko, V. V. Tereschenko, Yu. N. Kharzheev, D. Chokheli, and A. N. Shalyugin, Increase in the

Light Collection from a Scintillation Strip with a Hole for the WLS Fiber Using Filling Materials of Various Types//Physics of Particles and Nuclei Letters 2017, Vol.14, No.1, pp.139-143
3. Photoelectron yields of scintillation counters with embedded WLS fibers read out with silicon photomultipliers. A.Artikov et al, NIM A890 (2018) 84-95.
4. A. Artikov, V. Baranov, Yu. Budagov, M. Bulavin, D. Chokheli, Yu.I. Davydov, V. Glagolev, Yu. Kharzheev, V. Kolomoets, A. Simonenko, Z. Usubov, I. Vasiljev, Light yield and radiation hardness studies of scintillator strips with a filler / arXiv:1711.11393v1 [physics.ins-det] 30 Nov 2017. To be published in NIM A
5. Yuri Kharzheev, Scintillation Detectors in Modern High Energy Physics Experiments and Prospect of Their use in Future Experiments// Journal of Lasers, Optics, Photonics 2017 Vol.4 issue 1 1000148
6. Yu. N. Kharzheev, Radiation Hardness of Scintillation Detectors Based on Organic Plastic Scintillators and Optical Fibers (review) to be published in ЭЧАЯ 2019 Т.50 №1 стр.42-76 и Physics of Particles and Nuclei 2019, vol.50, No.1 pp.42-76
7. N. Atanov et al., “Measurement of time resolution of the Mu2e LYSO calorimeter prototype”, Nucl. Inst. Meth. A 812 (2016), 104.
8. N. Atanov et al., “Design and status of the Mu2e electromagnetic Calorimeter”, Nucl. Inst. Meth. A 824 (2016), 695.
9. N.Atanov et al., “Characterization of a prototype for the electromagnetic calorimeter of the Mu2e experiment” IL NUOVO CIMENTO 39 C (2016) 267
10. N. Atanov et al, “Energy and time resolution of a LYSO matrix prototype for the Mu2e experiment” NIM A824, 11 July 2016, Page 684
11. N. Atanov et al, “Characterization of a 5 × 5 LYSO Matrix Calorimeter Prototype” IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 63, NO. 2, APRIL 2016, p.596
12. N. Atanov et al Design and test of the Mu2e undoped CsI + SiPM crystal calorimeter, NIM A.(2018), in print
13. M.Angelucci et al., “Longitudinal uniformity, time performances and irradiation test of pure CsI crystals” Nucl.Instrum.Meth. A824 (2016) 678
14. O. Atanova et al., “Measurement of the energy and time resolution of a undoped CsI + MPPC array for the Mu2e experiment”, 2017 JINST 12 P05007.
15. Baranov, V.A. et al., “A Tracker Prototype Based on Cathode Straw Tubes” Instrum. Exp. Tech. (2018) Volume 61, Issue 5, p 645. Original Russian Text © V.A. Baranov et al. , 2018, published in Pribory i Tekhnika Eksperimenta, 2018, No. 5, pp. 19–22.

As one can see from the titles the above papers reflect Dubna group contribution to the RnD and element tests of two key systems of the future Mu2e experiment, namely cosmic ray veto (CRV) system and electromagnetic calorimeter. The papers 1-6,15 are described results obtained 100 % Dubna group colleagues while other papers are made with our group strong contribution.

The total number of Mu2e papers published for 2016-2018 are about 35.
The total number of Muon g-2 papers published for 2016-2018 are about 25.

5. PhD theses: *List the PhD theses completed within the last 3 years, or expected to be completed within 2019, by JINR students within the project, giving the student name, thesis title and graduation year*.

Our young scientists Nikolay Atanov, Vladimir Baranov and Ilya Vasiliev are in the PhD preparation stage.

6. Talks:

6a. List the invited plenary talks given by members of the JINR group in 2016, 2017 and 2018 at international conferences, workshops…: give name and date of the Conference, title of talk and speaker name.

1. The 6th International Conference on Contemporary Physics”June 7-10, 2016, Ulaanbaatar, Mongolia, “New trends in using Scintillation counters in modern high energy experiments” Yu. Kharzheev

2. International conference "Astrophysics and Particle Physics" 2016, Dallas USA 8-10. December 2016 "Scintillation detectors in modern high-energy physics experiments and prospect their use in future experiments"Yu. Kharzheev.
3. International Conference "New trends in High-Energy Physics" Monternegro, Budva 24-30 September 2018 "Radiation Hardness of scintillation detectors based on organic plastic scintillators and optical fibers" Yu. Kharzheev
4. Baranov V.Y., JINR, "Research of properties undoped crystals CsI" Fifth International Conference ESMART 2016 "Engineering of Scintillation Materials and Radiation Technologies" , 26 - 30 September 2016
5. Vasilyev I.I., JINR, « The light yield of a long scintillation strip with WLS fiber embedded into the co-extruded hole » Fifth International Conference ESMART 2016 "Engineering of Scintillation Materials and Radiation Technologies" , 26 - 30 September 2016
6. N. P. Kravchuk, "Tracker prototype on a base of cathode straw", Fifth International Conference ESMART 2016 "Engineering of Scintillation Materials and Radiation Technologies", September 26-30, 2016, Minsk, Belarus.
7. 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
8. 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

6b. *Give a similar list for parallel talks.*

1. Atanov N.V., Ivanov S.V., Jmeric V.N., Nechaev D.V., Tereshchenko V.V. "Solar-blind photodetectors with AlGaN photocathodes for light registration in UVC range" conference NTIHEP-2016, Montenegro, Budva
2. Atanov N.V et al "The front-end electronics of the Mu2e electromagnetic calorimeter", conference NTIHEP-2016, Montenegro, Budva
3. A.Simonenko et al, «INCREASING THE LIGHT YIELD FOR SCINTILLATION STRIPS WITH WLS FIBER EMBEDDED INTO THE CO-EXTRUDED HOLE» New Trends in High Energy Physics, 2016, Montenegro, Budva
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.

7. Group size, composition and budget.

7a. *Present in a Table the list of JINR personnel involved in the project, including name, status (e.g. PI, researcher, post-doc, student, engineer, technician…) and FTE. Mention the total number of people in the collaboration.*

#	Name	status	Lab	Task	FTE(%)
1	Artikov A.M.	sen. researcher	DLNP	CRV, calorimeter	100
2	Atanov N.V.	researcher	DLNP	calorimeter, CRV	90
3	Baranov V.A.	sen. researcher	DLNP	Muon g-2	20
4	Baranov V.Yu.	researcher	DLNP	calorimeter, CRV	90
5	Budagov J.A	PI	DLNP	calorimeter, CRV	50
6	Chokheli D.	sen. researcher	DLNP	calorimeter, CRV	100
7	Davydov Yu.I.	PI	DLNP	calorimeter, CRV	70
8	Demin D.L.	sen. researcher	DLNP	calorimeter	20
9	Duginov V.N	sen. researcher	DLNP	Muon g-2	20

10	Glagolev V.V.	PI	DLNP	calorimeter, CRV	70
11	Kharzheev Yu.N.	sen. researcher	DLNP	CRV, calorimeter	100
12	Khomutov N.V.	PI	DLNP	Muon g-2	70
13	Kolomoets V.I.	engineer	DLNP	CRV, calorimeter	100
14	Krylov V.A.	sen. researcher	LRB	Muon g-2	50
15	Kuchinsky N.A.	sen. researcher	DLNP	Muon g-2	30
16	Shalyugin A.N.	engineer	DLNP	CRV, calorimeter	80
17	Simonenko A.V.	Post-doc	DLNP	CRV, calorimeter	80
18	Suslov I.A.	sen. researcher	DLNP	Calorimeter simul.	50
19	Tereschenko V.V.	researcher	DLNP	CRV, calorimeter	30
20	Usubov Z.	sen. researcher	DLNP	CRV, calorimeter sim.	50
21	Vasilyev I.I.	researcher	DLNP	CRV, calorimeter	90

The total number of people in the Mu2e collaboration is 242.

The total number of people in the Muon g-2 collaboration is 185.

7b. *Indicate the expected changes in the group size, if any, till the end of the currently approved project.*

7c. *Present the JINR group budget from 2018 till the end of the currently approved project in a Table specifying the main budget items (equipment, computing, salaries, common funds, travel…)*

PROJECT direct expenses:

#	Item	full cost	2018	2019	2020
1	Computer communication	-	-	-	-
2	Design works	300 MH	100 MH	100 MH	100 MH
3	Workshop	300 MH	100 MH	100 MH	100 MH
4	Materials	320 K$	105 k$	105 K$	110 K$
5	Equipment	195 K$	85 k$	65 K$	45 K$
6	Travel Expenses	180 K$	60 K$	60 K$	60 K$
	Total:	695 K$	250 K$	230 K$	215 K$

7d. *Indicate the use of JINR computing resources for the group and for the project if any.*

Mu2e: 6 PCs are used for experiment simulation and JINR experimental stands for R&D and QA tasks.

Muon *g-2*: 4 PCs and 2 dedicated servers are used for software development and experiment simulation.