NOvA experiment

1. Goals of the experiment:

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

The NuMI Off-axis ν_e Appearance (NOvA) is a two-detector accelerator long-baseline neutrino oscillation experiment designed to address a broad range of open questions in the neutrino sector through precision measurements of $\nu_\mu \rightarrow \nu_e$, $\nu_\mu \rightarrow \nu_\mu$ oscillations in both neutrino and antineutrino mode. NOvA physics scope comes mainly from the ν_e appearance and ν_μ disappearance measurements, as the observed rates of ν_e and ν_μ interactions provide information on:

- the ordering of the neutrino masses (whether the ν_3 state is heavier or lighter than the other two);
- the amount of CP violation present in the neutrino sector;
- whether the ν_3 state has more ν_μ or ν_τ admixture (whether θ_{23} is > or < than 45 degrees).

Outside of the primary goals, NOvA will also look for evidence of new physics, provide constraints on sterile neutrino models by measuring the total flux of active neutrinos at its downstream detector, monitor for supernova neutrino activity, perform neutrino-nucleus cross section measurements with a narrow-band beam, and pursue a variety of non-neutrino topics including searches for magnetic monopoles and hidden sector particles.

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

The complete 14 kton Far Detector and 290 ton Near Detector have been taking data since 2014, and a number of important measurements have been performed on the basis of statistics collected 8.85×10^{20} POT in neutrino and 6.9×10^{20} POT in antineutrino modes so far. NOvA sees 8σ electron neutrino and 4σ electron antineutrino appearance. A joint appearance and disappearance analysis for these data prefers normal hierarchy at 1.8σ, excludes $\delta CP = \pi/2$ at $> 3\sigma$ significance level and rejects the maximal mixing at 2.2σ and the lower octant at a similar level. By now NOvA observed no evidence for mixing with sterile neutrinos or antineutrinos from the neutral current channel.
Continuing the data collection, and importantly, altering neutrino and antineutrino beams, NOvA can unambiguously resolve the neutrino mass hierarchy at >95% C.L. for over a third of possible values of δ (3σ level by 2020). For other values of this CP violation parameter, NOvA will provide δ-dependent hierarchy determination plus improved measurements of θ_{13} , θ_{23}, $|\Delta m^2_{23}|$, and δ itself, which is also very important for global analysis of the neutrino oscillation data (running plan to 2024).

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.

The JINR group in NOvA has contributed significantly to the NOvA results.

- The NOvA electronics test bench was set up at JINR and provided important measurements of electronics parameters used for both simulation and calibration.
- Another test stand was constructed at JINR to measure properties of the liquid NOvA scintillator, mainly to determine Birk's coefficient, which defines the response of scintillator to passage of slow protons.
- The Remote Operation Center (ROC-Dubna) was setup at JINR, giving the possibility to fully participate in the data taking and quality monitoring from Dubna.
- The JINR computer infrastructure on the basis of GRID and Cloud technologies was developed. It is efficiently used for the home-based running of jobs and is also a part of the NOvA distributed computing resources system for the use at peak loads (e.g., before conferences).

Members of the JINR group are deeply involved in the ongoing analyses and in the preparation of new ones. This comprises:

- the basic oscillation analysis,
- Supernova,
- Slow monopole,
- Cosmic Ray and Near Detector physics teams.

They are also involved in the development of simulation and analysis software, and are serving as a Detector Simulation conveners, Offline and DAQ Software Release Managers, DAQ, DDT and ROC experts, etc.

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.

Alexander Olshevskiy, IB-representative (2013 – till now), students supervising (2013 – till now)
Oleg Samoylov, Deputy at JINR (2013 – till now), detector simulation group convener (2016 – till now), ROCs super-liaison (2016 – till now), ROC-Dubna liaison (2015 – 2016), students supervising (2013 – till now)
Alexander Antoshkin, ROC-Dubna liaison (2016 – till now), Dubna tests stand development (2016 – till now)
Nikolay Anfimov, Dubna test stands management (2015 – till now), ROC-Dubna hardware support (2015 – till now)
Nikita Balashov, IT-support and development at JINR Cloud and GRID infrastructure in contact to Fermilab computing (2014 – till now)
Liudmila Kolupaeva, NOvA experiment software release manager (2016 – 2017), NOvA experiment software manager (2017 – till now), students supervising (2018 – till now)
Evgeniy Kuznetsov, IT-support at JINR Cloud and GRID infrastructure (2016 – till now)
Andrey Sheshukov, DAQ release manager (2016 – 2017), ROC-Dubna software support (2016 – till now), students supervising (2018 – till now)

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.

The JINR team is planning to continue and extend its involvement in the NOvA data taking and analyses. As a part of this work we are planning maintenance of ROC-Dubna and the hardware test bench facility, as well as a further increase of the NOvA computing power at JINR to cope with the large amount of data, and the continuation of the aforementioned analyses.

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) NOvA Collaboration (M.A. Acero et al.), New constraints on oscillation parameters from νe appearance and νμ disappearance in the NOvA experiment // Phys.Rev. D98 (2018) 032012.
   JINR group participated in the nue analysis by developing and optimising the event selection criteria.
2) L. Kolupaeva, O. Samoylov, I. Shandrov, Matter effect in neutrino oscillations for long-baseline experiments // Phys.Part.Nucl.Lett. 14 (2017) no.7, 975-980.

In this paper published by JINR authors the matter effect and its role in Long-Baseline experiments are discussed and NOvA and DUNE experiments are considered in details.

3) O. Petrova, K. Kuzmin, V. Naumov, Quasielastic Neutrino–Nucleus Interactions in the Empirical Model of Running Axial Mass of the Nucleon // Phys.Part.Nucl. 48 (2017) no. 6, 995–997. ISSN: 1063-7796.
   In accelerator neutrino experiments, neutrino-mixing parameters are extracted from the counting rates of quasielastic (anti)neutrino scattering on nuclear targets. This paper, published by JINR authors, discuss the uncertainties of these rates in the model with an energy-dependent (or running) axial mass of the nucleon.
4) NOvA Collaboration (P. Adamson et al.), Constraints on Oscillation Parameters from νe Appearance and νμ Disappearance in NOvA // Phys.Rev.Lett. 118 (2017) no.23, 231801.
   JINR group participated in the nue analysis by developing and optimising the event selection criteria.
5) L. D. Kolupaeva, K. S. Kuzmin, O. N. Petrova, Igor M. Shandrov, Some uncertainties of neutrino oscillation effect in the NOνA experiment // Mod.Phys.Lett. A31 (2016) no.12, 1650077.
   Uncertainties related to the effect of neutrino coherent forward scattering in Earth's matter (MSW mechanism) and with the cross sections of quasi-elastic neutrino scattering on nuclear targets of the NOνA detectors are studied in this paper published by JINR authors. The NOνA sensitivity to the neutrino mass hierarchy and the CP violating phase is discussed.

Total number of the NOvA collaboration papers published in the period 2016-2018 (no conference proceedings) is 6. JINR group has sizeable contribution in 2 of them (namely, 1 and 4 from the list above) .

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.

- In 2018 we have had PhD thesis defence (graduation from Moscow State University “aspirantura”) of Alexander Antoshkin “Application of MAPD photodetectors in high energy experiments”.
- We are expecting 1 PhD thesis defence in 2019: Andrey Sheshukov with topic “Advanced Supernova detection system and physical reach in the NOvA experiment”

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) Liudmila Kolupaeva, “New neutrino oscillation results from the NOvA experiment”, Neutrinos in Physics, Astrophysics and Cosmology (Nu HoRIzons VII), Allahabad, India, 21-23 February, 2018.
2) Liudmila Kolupaeva, “First joint analysis of data from neutrino and antineutrino beam in the NOvA experiment”, DLNP Seminar in JINR, Dubna, Russia, 23 November 2018.
3) Andrey Sheshukov, “Non-oscillation physics in NOvA”, DLNP Seminar in JINR, Dubna, Russia, 5 April 2018.
4) Liudmila Kolupaeva, “Measurement of neutrino mass hierarchy and CP phase in lepton sector from the NOvA neutrino experiment”, DLNP Seminar in JINR, Dubna, Russia, 17 March 2018.
5) Oleg Samoylov, “Measurement of θ_{23} mixing angle in the NOvA”, DLNP Seminar in JINR, Dubna, Russia, 3 March 2018.
6) Lyudmila Kolupaeva, “Matter effect in neutrino oscillations for NOvA experiment”, 120th session of the JINR Scientific Council, Dubna, Russia, 7-9 September.
7) Alexander Olshevskiy, “Neutrino Physics lectures”, School on Nuclear Physics, 18 May 2017, Borovets (Bulgaria).

8) Igor Kakorin, “Running axial mass for CCQE neutrino-nucleus scattering”, Workshop on Global Fits to Neutrino Scattering Data and Generator Tuning (NuTune2016), Liverpool, UK.
9) Liudmila Kolupaeva, “Current results of the NOvA experiment”, 19th International Seminar on High Energy Physics (Quarks-2016), Pushkin, Russia, 29 May - 4 June 2016.
10) Oleg Samoylov, “The NOvA experiment”, UC JINR students program, Dubna, Russia, 20 July 2016.
11) Oleg Samoylov, “Current results of the NOvA experiment”, International Session-Conference of SNP PSD RAS "Physics of Fundamental Interactions", Dubna, Russia, 12-15 April 2016.
12) Olga Petrova, “Quasielastic neutrino-nuclei interactions and the approach of running nucleon axial mass”, International Session-Conference of SNP PSD RAS "Physics of Fundamental Interactions", Dubna, Russia, 12-15 April 2016.

6b. Give a similar list for parallel talks.

1) Andrey Sheshukov, “Detecting neutrinos from the next galactic supernova in the NOvA detector”, 4th International Conference on Particle Physics and Astrophysics (ICPPA-2018), Moscow, Russia, 22-26 October 2018.
2) Oleg Samoylov, “Current status for simulation chain of the neutrino events in the NOvA experiment”, 23rd International Conference on Computing in High Energy and Nuclear Physics (CHEP 2018), Sofia, Bulgaria, 9-13 July 2018.
3) Liudmila Kolupaeva, “Latest neutrino oscillation results from the NOvA experiment”, International School of Subnuclear physics, Erice, Italy, 14 - 23 June 2018.
4) Oleg Samoylov, “A review on latest NOvA results”, 20th International Seminar on High Energy Physics (Quarks-2018), Valdai, Russia, 27 May - 2 June 2018.
5) Liudmila Kolupaeva, ‘Event selection for the nue analysis in the NOvA experiment”, 22nd International Scientific Conference of Young Scientists and Specialists of JINR (AYSS-2017), Dubna, Russia, 23-27 April 2018.
6) Andrey Sheshukov, “Supernova neutrino detection in the NOvA experiment”, 22nd International Scientific Conference of Young Scientists and Specialists of JINR (AYSS-2017), Dubna, Russia, 23-27 April 2018.
7) Lyudmila Kolupaeva, “Анализ nue событий в эксперименте NOvA”, XXV Международная конференция студентов, аспирантов и молодых учёных «Ломоносов», Moscow, Russia, 9-13 April 2018.
8) Alexander Antoshkin, “Slow magnetic monopoles search in NOvA”, 21st International Scientific Conference of Young Scientists and Specialists of JINR (AYSS-2017), Dubna, Russia, 2-6 October 2017.
9) Alexander Antoshkin, “Test bench for measurements of the NOvA scintillator properties at JINR”, 21st International Scientific Conference of Young Scientists and Specialists of JINR (AYSS-2017), Dubna, Russia, 2-6 October 2017.
10) Olga Petrova, “East-West cosmic muon flux asymmetry in the Far Detector of NOvA”, 21st International Scientific Conference of Young Scientists and Specialists of JINR (AYSS-2017), Dubna, Russia, 2-6 October 2017.
11) Lyudmila Kolupaeva, “Настройка критериев отбора событий для анализа появления электронных нейтрино в эксперименте NOvA”, XXIV Международная конференция студентов, аспирантов и молодых учёных «Ломоносов», Moscow, Russia, 9-13 April 2017.
12) Lyudmila Kolupaeva, “Анализ чувствительности нейтринного эксперимента NOvA после первого года работы”, XXIII Международная конференция студентов, аспирантов и молодых учёных «Ломоносов», Moscow, Russia, 11-15 April 2016.
13) Alexander Antoshkin, “NOvA test bench at JINR”, XX International Scientific Conference of Young Scientists and Specialists (AYSS-2016), Dubna, Russia, 14-18 March 2016.
14) Nikita Balashov, “JINR LIT Computing Resources for NOvA”, XX International Scientific Conference of Young Scientists and Specialists (AYSS-2016), Dubna, Russia, 14-18 March 2016.
15) Lyudmila Kolupaeva, “Matter effect in neutrino oscillations for NOvA experiment”, XX International Scientific Conference of Young Scientists and Specialists (AYSS-2016), Dubna, Russia, 14-18 March 2016.

16) Oleg Samoylov, "ROC-Dubna for NOvA experiment", XX International Scientific Conference of Young Scientists and Specialists (AYSS-2016), Dubna, Russia, 14-18 March 2016.
17) Andrey Sheshukov, "Detecting galactic SuperNova with NOvA Far Detector", XX International Scientific Conference of Young Scientists and Specialists (AYSS-2016), Dubna, Russia, 14-18 March 2016.
18) Igor Shandrov, "Introduction into Multi-Model Earth Density Approach", XX International Scientific Conference of Young Scientists and Specialists (AYSS-2016), Dubna, Russia, 14-18 March 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	Tasks	FTE
1	Allakhverdian, Vladimir	student	DLNP	ND Physics, strange particles production	1.0
2	Amvrosov, Veniamin	student	DLNP	Numu oscillation analysis	1.0
3	Anfimov, Nikolay	researcher	DLNP	Det operations, test stand	0.3
4	Antoshkin, Alexander	junior researcher	DLNP	Det operations, test stand	1.0
				Exotics, slow monopoles	
				Det control, ROC-liaison	
5	Balashov, Nikita	computing engineer	LIT	Computing	0.3
6	Baranov, Alexander	computing engineer	LIT	Computing, cloud	0.1
7	Bilenky, Samoil	Professor	BLTP	Oscillation theory	0.1
8	Dolbilov, Andrey	computing engineer	LIT	Computing, emergency	0.1
9	Kakorin, Igor	researcher	BLTP	Det simulation, GENIE	0.5
10	Kalitkina, Anastasia	student	DLNP	Nue oscillation analysis	1.0
11	Klimov, Oleg	researcher	DLNP	Reco, proton ID	0.5
12	Kolupaeva, Liudmila	PhD student	DLNP	Nue oscillation analysis	1.0
				Software, release manager	

13	Kullenberg, Christopher	researcher	DLNP	ND Physics, coh pion	1.0
				CVN development	
14	Kuzmin, Konstantin	researcher	BLTP	Det sim, cross sec theory	0.1
15	Kuznetsov, Evgeny	computing engineer	LIT	Computing hardware	0.3
16	Matveev, Victor	Professor	BLTP	Theory, Coll management	0.1
17	Morozova, Anna	junior researcher	DLNP	Exotics, CR muons	1.0
18	Naumov, Vadim	Professor	BLTP	Osc and cross sec theory	0.3
19	Olshevskiy, Alexander	PI	DLNP	Coll and JINR tasks management, IB-rep	0.5
20	Petropavlova, Maria	student	DLNP	Exotics, SN detection	1.0
21	Petrova, Olga	junior researcher	DLNP	Exotics, CR muons	1.0
				Det sim, cross sec calc	
22	Samoylov, Oleg	PI	DLNP	Det sim, co-convener	0.7
				Det control, ROC-manager, Super ROC-liaison	
				Coll manag, deputy at JINR, students supervising	
23	Sheshukov, Andrey	researcher	DLNP	DAQ, software dev/support	0.7
				DDT, supernova trigger development	
				Exotics, SN detection	
24	Sotnikov, Albert	electronic engineer	DLNP	Det operations, test stand	0.2
	TOTAL				**13.8**

The NOvA international collaboration is made up (by July 2018) of 238 scientists and engineers from 49 institutions in seven countries.

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

In 2019 we expect additional 1-2 bachelor students to join the 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…)

Наименование узлов и систем установки, ресурсов, источников финансирования			Стоимость узлов установки (тыс.долл.) Потребности в ресурсах	Предложения Лаборат распределению финан и ресурсов		
				1 год	2 год	3 год
Основные узлы и оборудование	1. Модернизация Virtual Control Room в ОИЯИ, связь, замена части компьютеров и офисного оборудования, расходные материалы		30.0	10.0	10.0	10.0
	2. Лабораторное оборудование для измерений и тестов электроники и сцинтиллятора (крейт, генератор, блоки электроники и другие)		15.0	5.0	5.0	5.0
	3. Вычислительная инфраструктура (вычислительные серверы, диски для хранения данных)		195.0	65.0	65.0	65.0
Необходимые ресурсы	*норм о-часы*	ОП ОИЯИ ООЭП ЛЯП	*2100* *2400*	*700* *800*	*700* *800*	*700* *800*
	тыс. долл.	Визиты в Fermilab, конференции и другие совещания	180.0	60.0	60.0	60.0
Источники финансирования	Бюджет	Затраты из бюджета	**390.0**	**130.0**	**130.0**	**130.0**
	Внебюджетные средства	Вклады коллаборантов, средства по грантам и другие	**30.0**	**10.0**	**10.0**	**10.0**

№ № пп	Наименование статей затрат	Полная Стоимость Нормочасы Тыс. долл.	1 год	2 год	3 год
1.	Ускоритель	-	-	-	-
2.	ЭВМ	-	-	-	-
3.	Комп. связь (тыс. долл.)	6.0	2.0	2.0	2.0
4.	*ООЭП ЛЯП (нормочасы)*	*2400*	*800*	*800*	*800*
5.	*ОП ОИЯИ (нормочасы)*	*2100*	*700*	*700*	*700*
6.	Материалы (тыс. долл.)	9.0	3.0	3.0	3.0
7.	Оборудование (тыс. долл.)	225.0	75.0	75.0	75.0
8.	Оплата НИР (тыс. долл.)	-	-	-	-
9.	Командировочные расходы (тыс. долл.)	150.0	50.0	50.0	50.0
	Итого по прямым расходам (тыс. долл.)	**390.0**	**130.0**	**130.0**	**130.0**

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

The JINR cloud and Tier-2 computing infrastructures provide the NOvA experiment with additional resources for batch job processing. While both of them run mostly data production jobs, the cloud infrastructure is also used by the local NOvA group in interactive mode, including such user cases as data analysis and software development. The total cloud and Tier-2 contribution at JINR sums up to over 1.2 million of CPU wall hours spent only on NOvA production job processing for the past year (compared to 2.5 million provided by Czech FZU site - the largest grid site after FNAL itself).