OPERA and DsTau experiments

1. Goals of the experiment:

1a. The main goal of the **OPERA experiment** was an unambiguous detection of the nu-mu to nu-tau oscillations (responsible for the atmospheric neutrino deficit) through a direct observation of the tau neutrinos appearance in the muon neutrino beam at a distance from the beam production. The experiment had been taking data in 2008-2012. About 18000 neutrino interactions were fully reconstructed and studied with sub-micrometric resolution. In 2015, the OPERA collaboration had reported on the discovery of the nu-mu to nu-tau oscillations with a statistical significance of 5.1 standard deviations. In 2018, the collaboration had presented the results of the new advanced analysis of the data and reported on 10 nu-tau events detected thus confirming and even improving the previously reported statistical significance up to 6.1 standard deviations. The collaboration presented several other important results - on nu-mu to nu-e oscillations and limits on the non-standard oscillations and sterile neutrino, atmospheric muons charge asymmetry, seasonal muon flux variations, hadron multiplicity in neutrino nucleus interactions and others.

DsTau project aims at improvement of the tau neutrino interaction cross section measurement studying the process of tau neutrino production in high energy proton nuclei interactions. Although it is known that tau neutrino are being produced in the decays of Ds mesons, the cross section of their production in the proton-nuclei interactions are still poorly measured. Improving accuracy of this cross section will allow to predict tau neutrino content in the future neutrino beams - at CERN (SHiP, FASER…), at FNAL (DUNE), and for HyperK in Japan. For the last two - the tau neutrino contamination is an important source of the background. Also the better knowledge about tau neutrino production is needed for the IceCube data understanding. The improvement of the accuracy of the tau neutrino interaction cross section measurement will allow testing of the Lepton Universality principle in the lepton sector.

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

OPERA is a first class international experiment conducted by the international collaboration of ~200 physicists from 11 countries in the Gran Sasso underground laboratory of INFN with the beam provided from CERN. The results of the experiment, their contribution to the general neutrino oscillation paradigma are highly appreciated by the physics community worldwide.

The DsTau project is a smaller scale experiment but it is also an international collaboration of about 25 physicists from 5 countries: Japan, Romania, Russia, Switzerland, Turkey. The groups from Russia (JINR) and Romania (ISS) have a protocol of cooperation.

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.

- JINR actively participated in the OPERA Target Tracker detector creation (modules assembly, detector assembly, principal contribution in the detector calibration)
- JINR has created the software of the Target Tracker data analysis and was responsible for the electronic detectors analysis and estimation of the event vertex position ("brick finding task") - BrickFinder package
- JINR created the software for the graphical presentation of the events - EventDisplay package.
- JINR created the scanning lab equipped with two automatic scanning stations and performed the OPERA emulsion data analysis
- JINR has proposed the improved method of the neutrino event time registration which allowed to perform correct measurement of the neutrino velocity after the hardware bug elimination.

- JINR developed software algorithm for the electron neutrino energy estimation using the Target Tracker data
- JINR made a principal contribution in a realization of OPERA data presentation in CERN Open Data project - OPERA is the only experiment besides those of LHC which made its data publically available through this project.
- JINR made principal contribution in the nu-mu to nu-e analysis and preparation of the publications.

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.

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- Yu.Gornushkin - Deputy Spokesperson (2012-now)
- Yu.Gornushkin - Institutional Board member (2004-now)
- Yu.Gornushkin - Executive Board member (2009-now)
- Yu.Gornushkin - Webmaster of the OPERA site (2012-now)
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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.

OPERA

The OPERA collaboration has completed the mission, the final papers are being published.

DsTau

The experience in the use of nuclear emulsion technique and tau neutrino related data analysis accumulated during last 15 years as well as unique hardware equipment are going to be applied in new projects: DsTau - aiming at a study of tau neutrino production in the proton-nuclei interactions and improving the accuracy of the tau neutrino interaction cross section. The project has a great potential for charm particles decay study as well.

In the DsTau project JINR group participates in the experiment preparation, Monte Carlo background estimation and development of the algorithms for its suppression. The development of the algorithms for the event reconstruction is also under way. DsTau has taken data in the pilot run (about 10% of the goal statistics) in 2018 and now the collaboration analyses the data to finally prove the project visibility. In spring 2019 SPSC will consider approval of the experiment based on the performance achieved with the pilot run.

In case of DsTau approval, JINR group will also work on creation of the beam monitor detector based on scintillating fibers for the main run in 2020-2021.

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. Final Results of the OPERA Experiment on $\nu\tau$ Appearance in the CNGS Neutrino Beam
OPERA Collaboration (N. Agafonova (Moscow, INR) *et al.*). Apr 13, 2018. 7 pp.
Published in **P**hys.Rev.Lett. 120 (2018) no.21, 211801
- Yu.Gornushkin - the internal referee

2 Final results of the search for $\nu\mu \rightarrow \nu e$ oscillations with the OPERA detector in the CNGS beam
OPERA Collaboration (N. Agafonova (Moscow, INR) *et al.*)
Mar 30, 2018 - 15 pages, JHEP 1806 (2018) 151
- S.Vasina - corresponding author

There were 4 papers published by the OPERA collaboration in the last 3 years.
DsTau experiment is just being started now - no publications in journals yet.

5. PhD theses:

Dmitrievsky S. "Search for neutrino interactions and neutrino properties with the electronic detectors in the OPERA experiment", 2015

Vasina S. "Study of nu-mu to nu-e oscillations in the OPERA experiment", expected in 2019

6. Talks:

6a. Invited plenary talks given by members of the JINR group in 2016, 2017 and 2018 at international conferences, workshops…:

1. S.Vasina “More results from the OPERA experiment”, XIIIth Rencontres du Vietnam: Neutrino Physics, Quy Nhon, Vietnam, 2017

2. S.Vasina “Directional detection of DM with the nuclear emulsion base detector (NEWSdm)”, XIIIth Rencontres du Vietnam: Neutrino Physics, Quy Nhon, Vietnam, 2017

6b. Parallel talks.

1.Yu.Gornushkin “Study of tau neutrino production in proton nuclei interactions”, VI International Conference on Particle Physics and Astrophysics (ICPPA-2018), Moscow, Russia

2.Dmitrievsky S. "New results from the OPERA experiment", "6th International Conference on New Frontiers in Physics", 17–29 August 2017, Kolymbari, Crete, Greece

3.Vasina S. “New results from the OPERA experiment in the CNGS neutrino beam”, VI International Conference on Particle Physics and Astrophysics (ICPPA-2018), Moscow, Russia

4.S.Vasina, Discovery of Nu_mu to nu_tau oscillations in the OPERA experiment, Международная Сессия-конференция Секции ядерной физики ОФН РАН, ОИЯИ, Дубна, Россия, 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.

Yu.Gornushkin - PI - 0.5

S.Dmitrievsky - researcher - 0.5

S.Vasina - researcher - 1

E.Sitnikova - student - 1

A.Sotnikov - engineer - 0.2

There are about 150 members in the OPERA collaboration now.

There are about 25 people in the DsTau collaboration

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…)

Currently there is no approved project corresponding to OPERA/DsTau. It is being conducted as an activity with the budget of about $10k for travel and about $3k for the equipment and materials.

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

So far only local computing resources and the resources of the collaboration were in use. There are plans to use JINR resources as the analysis of the data taken in the pilot run of the DsTau is too large.