Neutrino and Astroparticle Physics: An Overview of Serbia's Contributions

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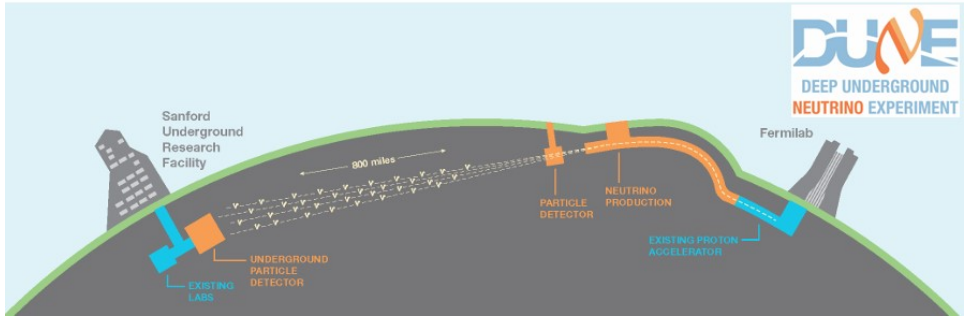
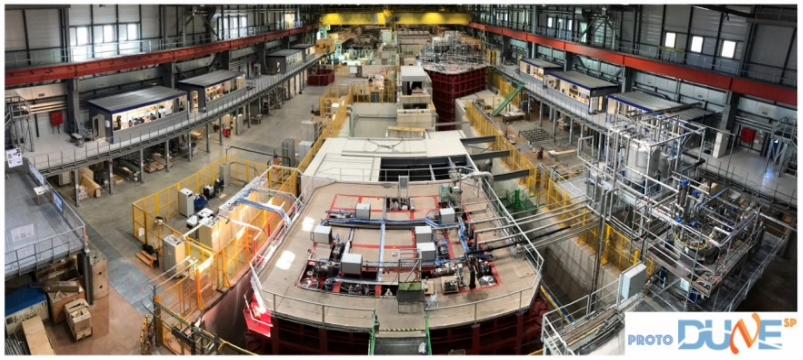
"RECFA visit to Serbia", Belgrade 29.11.2024.



DUNE (Future in the US)



NP04 ProtoDUNE-SP (Running at CERN)

Scientists from Serbia are participating in four projects focused on neutrino physics and astroparticle physics:

- **DUNE (Deep Underground Neutrino Experiment)**
- **ProtoDUNE (CERN)**
- **Baikal Deep Underwater Neutrino Telescope (Baikal-GVD)**
- **DARWIN: dark matter wimp search with liquid xenon**

Baikal-GVD (Raning in Russia)

XENON LZ(ZEPELIN LUX) DARWIN

The Deep Underground Neutrino Experiment (DUNE) is a leading-edge, international experiment for neutrino science. Discoveries over the past half-century have put neutrinos, the most abundant matter particles in the universe, in the spotlight for further research into several fundamental questions about the nature of matter and the evolution of the universe — questions that DUNE will seek to answer.

The DUNE Science Collaboration is currently made up of over 1400 collaborators from over 200 institutions in over 30 countries plus CERN.

Participation of University of Novi Sad Faculty of Sciences (UNSPMF) and Institute of Physics Belgrade (IPB) from 2020.

Team Leader: Prof- dr Nataša Todorović

Research Interests: CP-violation studies and low-energy physics studies (supernova and proton-decay searches), simulation and analysis in future DUNE.

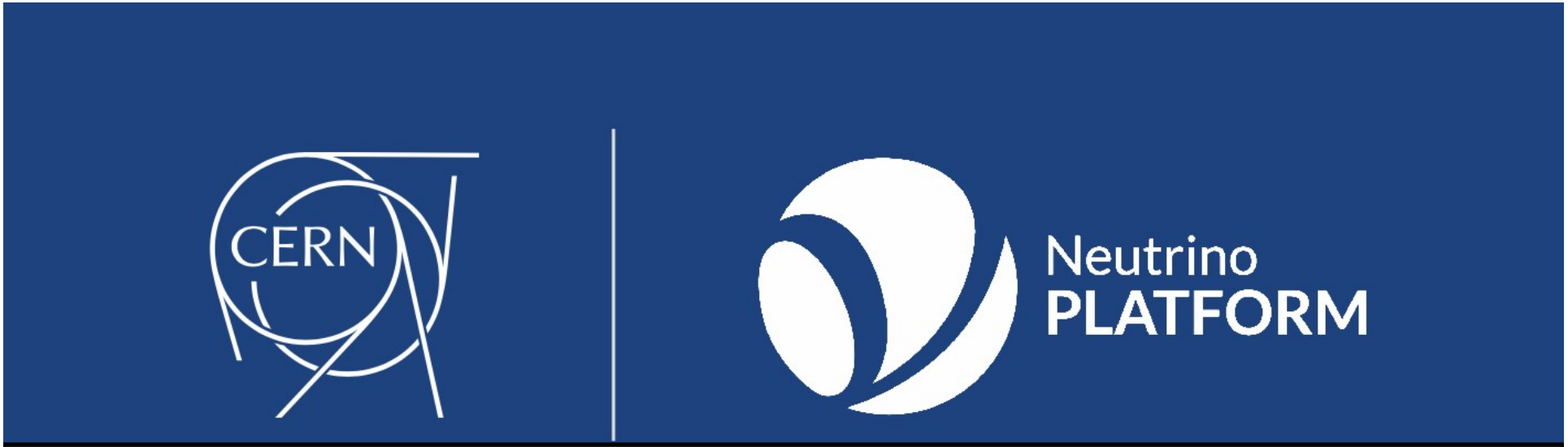
Team members:

4 senior scientist : Prof. dr Nataša Todorović (UNSPMF), Prof. dr Jovana Nikolov (UNSPMF), Prof. dr Nikola Jovančević (UNSPMF), Dr Lidija Živković (IPB)

1 PhD student: Aleksandar Rikalo (UNSPMF)

Funding grants: GENESIS project (Science Fund of the Republic of Serbia, *Serbian Science and Diaspora Collaboration Program: Knowledge Exchange Vouchers (2020-2023)*

Currently without dedicated funding from the responsible Ministry.



CERN's Neutrino Platform houses a prototype of the DUNE, ProtoDUNE, which is designed to test and validate the technologies that will be applied to the construction of the DUNE experiment in the United States. ProtoDUNE will use the proton beam from the Super Proton Synchrotron to test the detecting of charged particles.

The projects at CERN neutrino Platform:

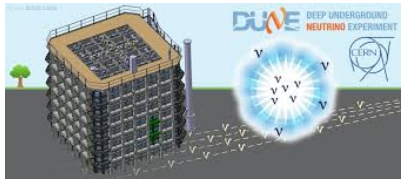
Neutrino PLATFORM

Approved by the SPSC:

NP01 (WA104): ICARUS as far detector for the SBN
NP02 (WA105/ProtoDUNE-DP): demonstrator and engineering prototype for a double-phase LAr TPC
NP03 (Plafond): Generic R&D framework
NP04 (ProtoDUNE-SP): demonstrator and engineering prototype on for a single-phase LAr TPC
NP05 (BabyMIND): Magnetised muon spectrometer for the WAGASCI experiment at T2K

LoI-243 ArgonCube: a modular LAr-TPC R&D
EoI-015 Near Detectors based on gas TPCs for neutrino long baseline experim

NP-04/ProtoDUNE CERN



The goal of the NP04 collaboration is the testing and calibration of the ProtoDUNE detector, as well as preparation for the main DUNE experiment.

The NP04 collaboration contributes to the development of technology and methodology necessary for the successful implementation of the DUNE experiment, which aims to address key questions related to neutrinos and their properties.

Participation: University of Novi Sad Faculty of Sciences (UNSPMF) from 2023.
Team Leader: Prof. dr Nataša Todorović
Research Interests: detector testing, proton-decay searches, simulation and analysis.
Team members:
3senior scientists : Prof. dr Nataša Todorović, Prof. dr Jovana Nikolov (UNSPMF), Prof. dr Nikola Jovančević (UNSPMF)
2 ECR s: Dr Andrej Vraničar (UNSPMF), Dr Miloš Travar (IPB)
1 PhD student: Aleksandar Rikalo (UNSPMF), visited NP04 ProtoDUNE several times during 2023 and 2024 as part of the Cold TPC Cold Electronics Consortium. He worked on setting up the experiment and ensuring data quality control.
Co-authors on 7 publications since joining the DUNE collaboration.

Currently without dedicated funding from the responsible Ministry.

NEUTRINO PROGRAM

The European Organization for Nuclear Research (CERN)
as the Host Laboratory of NP04

and

University of Novi Sad Faculty of Sciences participating in NP04

declare that they agree on the terms of this Addendum to the Memorandum of Understanding for Collaboration in the Neutrino Program at CERN, governing participation in the study of the feasibility of a new generation of detectors and technologies for future neutrino experiments.

Done in Geneva on 23 March 2023

for CERN

by Joachim Mnich
Director for Research and Computing

Done in Novi Sad on 20 March 2023

for University of Novi Sad Faculty of Sciences

by Milica Pavkov Hrvojević
Dean of the Faculty of Sciences

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Fermilab

March 14, 2023

Professor dr Nataša Todorović
University of Novi Sad, Faculty of Sciences
Department of Physics, Nuclear Physics Group
Trg Dositeja Obradovića 4
2100 Novi Sad, Serbia

Dear Professor Todorović,

I am very happy to welcome you and your group to the DUNE TPC Cold Electronics Consortium. I expect that your group will play an important part in the activities of the consortium at the CERN Neutrino Platform over the next two years. During this time we will finish commissioning the TPC front end and readout electronics for both the horizontal drift and the vertical drift protoDUNE-II detectors. We will also start QC testing of approximately 10% of the production anode plane assemblies for the first large DUNE far detector using the NP04 cold box.

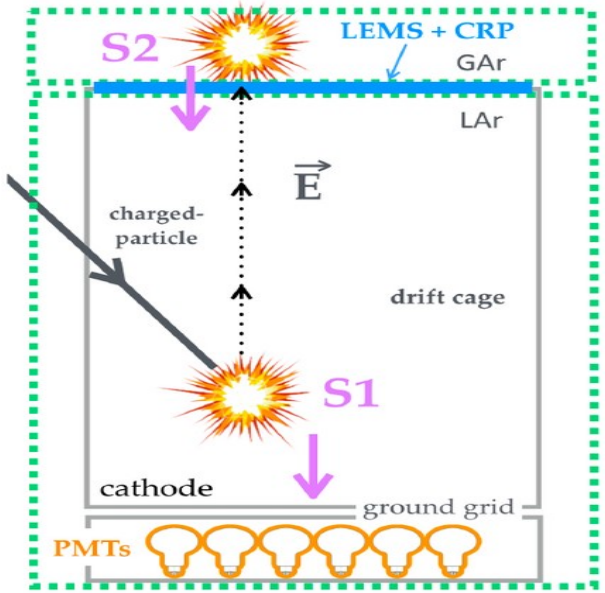
Sincerely,

David Christian
Head, TPC Cold Electronics Consortium

Fermi National Accelerator Laboratory / Kirk and Pine Street / P.O. Box 500 / Batavia, IL 60510 / 630.840.3000 / www.fnal.gov /
Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Liquid Argon Time Projection Chamber and Proton Decay Signatures

Charged particles + LAr → Ionization + Scintillation



Charged particles are accelerated in an electric field

Detection through light or charged particles

3D reconstruction of tracks and interaction identification

Cryogenic technology

Exceptional purity of Ar (argon)

- Simulation of proton decay at DUNE LArTPC

$$p \rightarrow K^+ \bar{\nu}$$

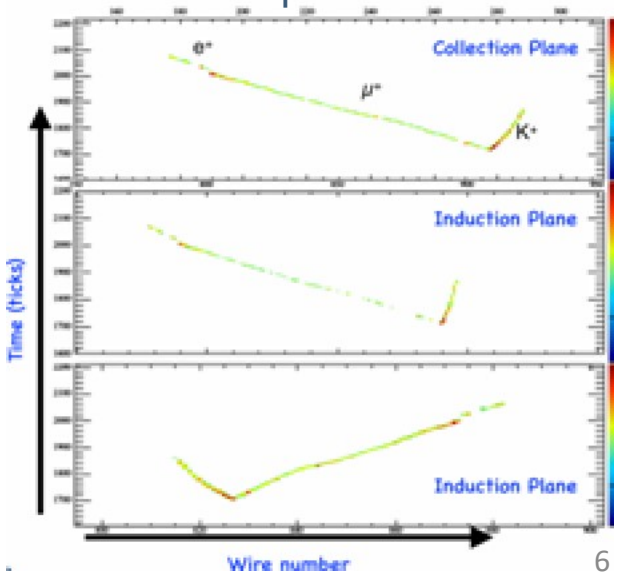
- Proton decay from Ar nucleus
- Simulation of nulear effects

$$p \rightarrow K^+ \bar{\nu}$$

$$K^+ \rightarrow \mu^+ \bar{\nu}_\mu$$

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

Dual phase LAr TPC



Proton Decay Signatures -PhD Thesis Overview

- **Dissertation Title**:
  "**Searching for Proton Decay $p \to K^+\bar{\nu}$ in ProtoDUNE Experiment Using Machine Learning and Neural Networks**", candidate Aleksandar Rikalo, under the mentorship of prof. dr Nataša Todorović and dr Lidija Živković. The topic of the PhD thesis was approved by the University of Novi Sad in July 2024.
- **Key Objectives**:
  - **Detection and Reconstruction**:
    - Identify low-energy kaons and their decay products (K^+,μ^+, etc.).
    - Measure energy deposition (dE/dx) and residual range in LArTPC detectors.
  - **Simulation and Method Development**:
    - Develop new machine learning and neural network algorithms to enhance signal detection and background reduction.
- **Experimental Platform**:
  - Use data from ProtoDUNE LArTPC.
  - Validate the feasibility of argon detectors for proton decay studies.
- **Anticipated Outcomes**:
  - Precise determination of proton decay signatures.
  - Improved understanding of kaon-proton discrimination.
  - Contribution to the experimental toolkit for DUNE, advancing global efforts in neutrino and particle physics.

Astronomical Observatory Belgrade

Future collaboration of the Astronomical Observatory with the Baikal-GVD telescope

Participation: Astronomicla Observatory Belgrade and and Institute of Physics Belgrade (IPB)

Team members:

AOB: L .Popović, J.Petrović, S. Samurović, B. Vukotić, A. Mitrašinović, M. Grozdanović

IPB: L. Beemster

Possible projects

•Source stacking analysis that will be used to identify Active Galactic Nuclei (AGNs) as cosmic accelerators and sources of high-energy neutrinos observed by the Baikal neutrino telescope

•Optical follow-up observations (Astronomical Station Vidojevica) of AGNs identified as possible neutrino sources by the Baikal telescope

Source stacking studies – Baikal telescope

J.Petrović (AOB), L. Beemster (IPB) for the ANTARES coll – 2190 neutrinos and 69 UHECRs directions (Pierre Auger Obs)

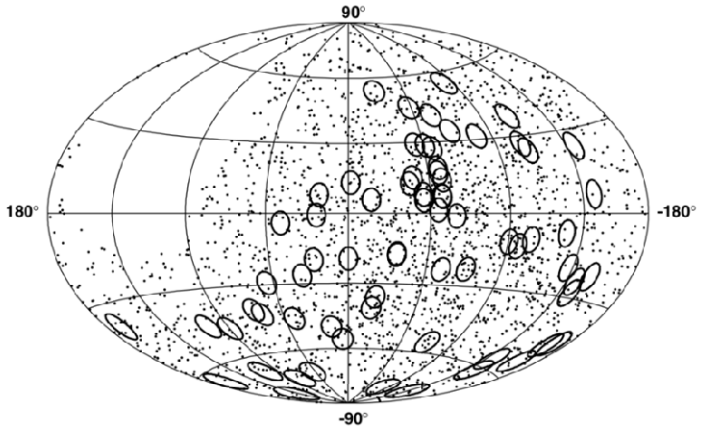
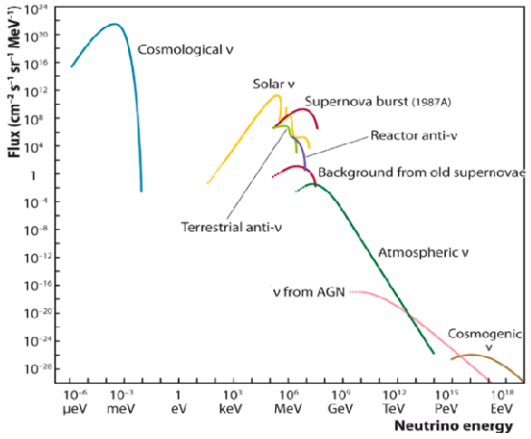
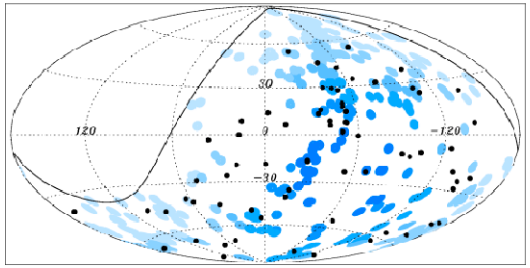


Figure 5. On this sky map in Galactic coordinates, neutrino events are represented with black dots and angular search bins of 4°.9 centered on the observed UHECRs with black circles.





69 UHECRs directions
Pierre Auger coll, 2010, Aph, 34,314

- Defining several sets of objects: various sets of AGNs, for example blazars, BL Lacs or observed Ultra-High-Energy Cosmic Rays (UHECRs) directions
- Developing Monte Carlo software and analysis that can be applied on blinded observations performed by the Baikal telescope
- Determining the discovery potential and signal limits needed for discovery
- Applying source stacking method on the Baikal telescope neutrino events sets
- Establishing the signal significance and the upper flux limit from all selected object sets

Optical follow-up – AS Vidojevica

Location:
Mt. Vidojevica near Prokuplje, elevation: 1150m
Coordinates: longitude: 21° 33' 20.4" latitude: 43° 08' 24.6"

Follow up observations for neutrino events detected with Baikal-GVD: The observations will be performed in the optical band with the 1.4m Milanković telescope at the Astronomical Station Vidojevica.

Also planned:
collaboration on the Baikal-GVD telescope data processing and Baikal-GVD telescope equipment maintenance and upgrades.

Delegation from the Baikal-GVD collaboration (JINR institute, Dubna, Russia) headed by dr. Dmitry Naumov visited AOB in October 2023 and October 2024. Delegation from the AOB visited JINR institute in Dubna in February 2024.

ASTROPARTICLE PHYSICS

"The DARWIN project aims at the realisation of a future astroparticle observatory in Europe as identified in the APPEC Roadmap. The goal is to design and construct the ultimate dark matter detector, using a multi-ton target of liquid xenon for the direct detection of particle dark matter in a sensitive time projection chamber. "

Participation of Vinca Institute in the future particle observatory DARWIN
Fully signed MoU
Team Leader: Mila Pandurovic
Research Interests:
Detector simulation development
Radon mitigation
2 professors Mila Pandurovic, Biljana Antunovic
1 postdoc Slobodan Milutinovic
Tritium mitigation planned
two professors: Marija Jankovic
Natasa Sarap

XZLD

Unification “world leading collaborations joining forces in the search for Dark Matter”
XENON LZ(ZEPELIN LUX) DARWIN
MoU, collaboration formed

Team Leader: Mila Pandurovic
Continuation of the DARWIN studies
Research Interests:
Detector simulation development
Radon mitigation
2 professors Mila Pandurovic, Biljana Antunovic
1 postdoc Slobodan Milutinovic
Tritium mitigation
two professors: Marija Jankovic
Natasa Sarap

Summary

I. In Serbia, four research groups are actively engaged in neutrino physics and astroparticle physics.
II. The capacity for more active involvement in experimental collaborations is limited by insufficient funding to support the research groups' presence at experimental sites, as well as by constrained resources for financing participation in these projects.
III. As all experiments are currently in the development phase, there is a pressing need to formulate a comprehensive long-term strategy to ensure sustainable participation and adequate funding for Serbian researchers involved in these initiatives.

Thank you for your attention!