

Nuclear Physics in Serbia



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Introduction

- There are few research groups in Serbia that are involved in nuclear related experiments fundamental and applied research.
- The focus on the main activities of some laboratories from 3 institutions:
 - University of Novi Sad, Faculty of Sciences
 - University of Belgrade, Institute of Nuclear Sciences Vinča
 - University of Belgrade, Institute of Physics
- However there are even more groups from other institutions that are active in this area.



University of Novi Sad, Faculty of Sciences Nuclear Physics Group



Educational curricula of UNS NPG

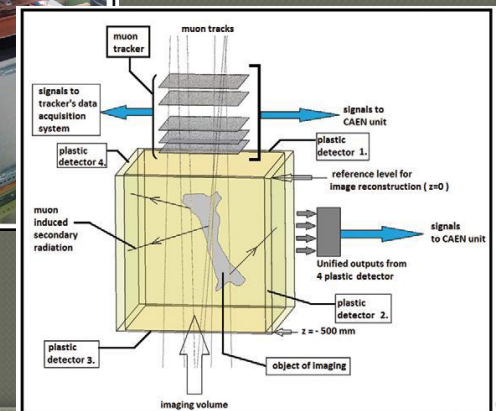
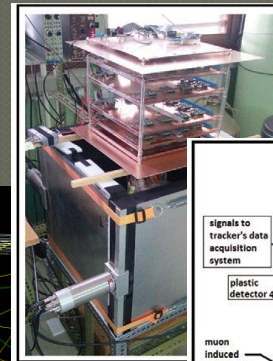
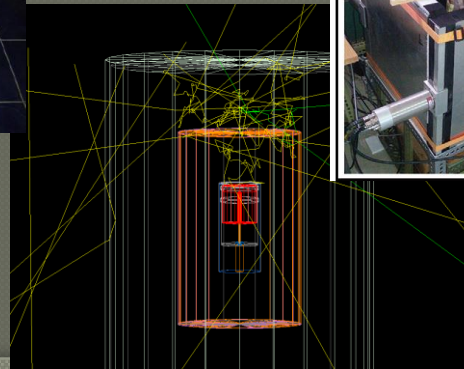
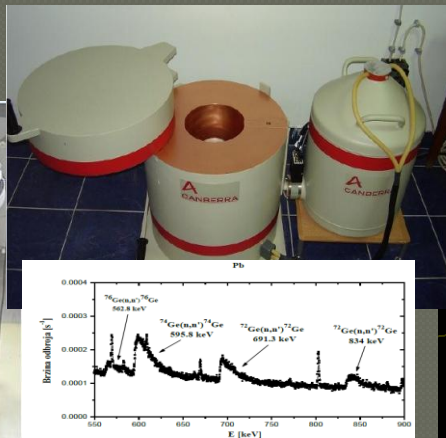
- Master and PhD studies in Nuclear Physics
- Every year we have around 10 MSc students in Nuclear Physics and 3-5 new PhD students in Nuclear Physics
 - fundamental research topics in collaboration with foreign research institutes/organizations (EC JRC, CERN, GANIL, DUBNA, GSI Darmstadt, etc.)
 - Applied nuclear physics topics related to alpha/beta and gamma spectrometry and different applications in nuclear safety and security
- Total number of staff at UNS NPG is:
 - 4 full professors, 1 associate professor, 3 assistant professors, 2 research fellows



Around 10-15 research publications per year.

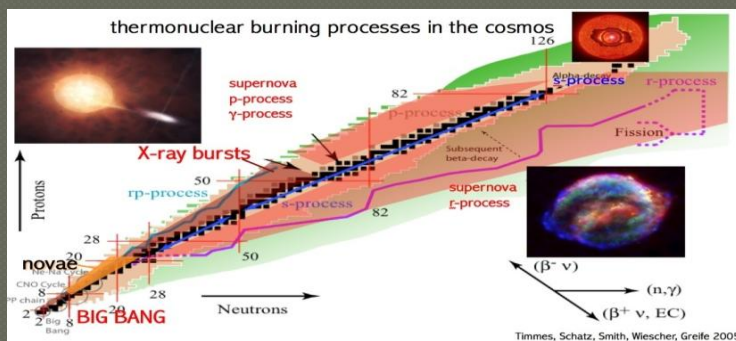
Measurements in the low background lab in Novi Sad

- Development of new, improved LSC methods for the measurement of alpha and beta emitters
- Study of gamma ray activity induced by cosmic radiation (muon and neutron interactions with HPGe detector and surrounding materials)
- Investigations of ultra-low-background events of detector systems for underground experiments
- Exploration of cosmic ray muon induced events by coincidence detection systems
- Imaging of organic structures by cosmic ray muons
- Geant4 simulation of HPGe detector system, Monte Carlo simulations of nuclear events
- Application of gamma spectrometry as a non destructive tool in nuclear forensics
- Input to the Lab Resources Survey done by LDG/ECFA Detector R&D Infrastructure Panel submitted.



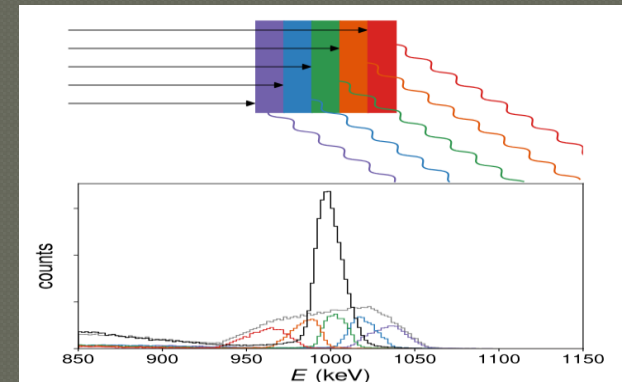
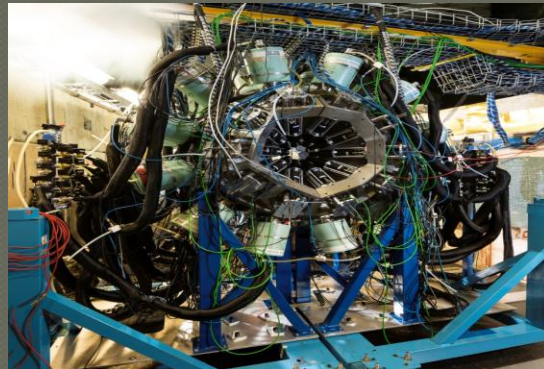
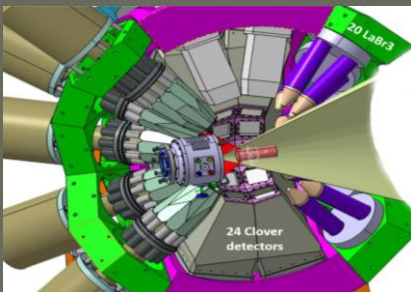
Participation of UNS NPG in nuclear structure measurements

- Spectroscopic data and nuclear structure studies using $(n_{th}, 2\gamma)$ reaction and two-step gamma cascade method
 - In collaboration with: PGAA facility of Centre for Energy Research (MTA EK), Budapest, Hungary and Technische Universität München, Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II), Garching, Germany
 - Obtaining accurate experimental values of the level scheme, level density and radiative strength functions is necessary for fission, astrophysical studies etc.
- CERN - ISOLDE collaboration
 - Magnetic moment measurements on Low temperature nuclear orientation experiment NICOLE (out of operation since 2019)
 - Exploring possibilities to join some other teams in ISOLDE collaboration – 3 active members from UNS NPG + PhD students



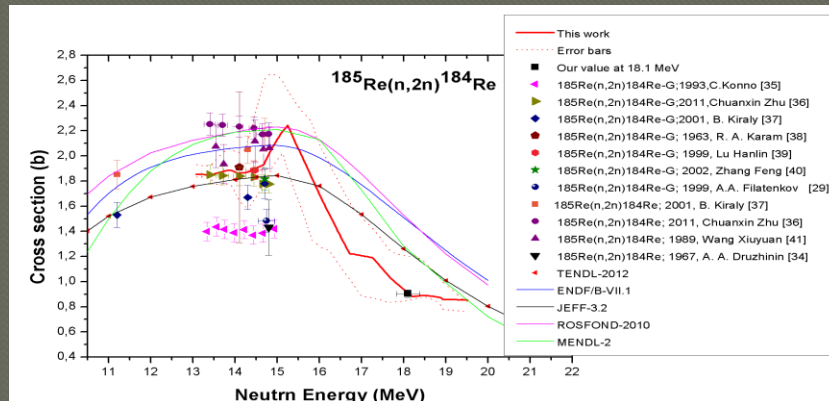
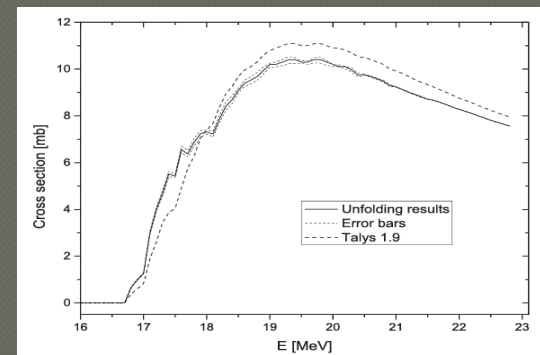
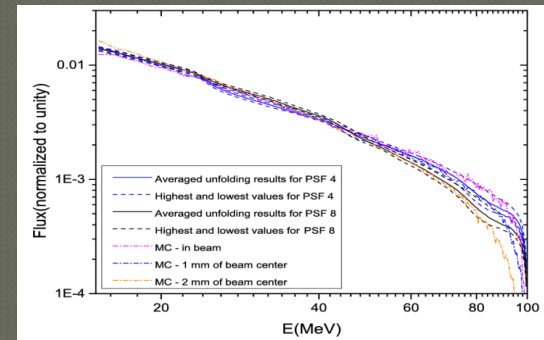
Participation of UNS NPG in nuclear structure measurements

- The v-BALL project Study of neutron induces reaction and fission and ALTO facility, Orsay, France
- Cooperation with GSI, Germany:
 - Researchers from UNS NPG will participate in the LISA project (Lifetime measurements with Solid Active targets)
 - two of our doctoral students are working on their doctoral theses in cooperation with GSI:
 - Investigation of the nuclear structure of nuclei around N=20 inversion islands
 - Complete spectroscopy of ^{136}Ba for investigation of double beta decay



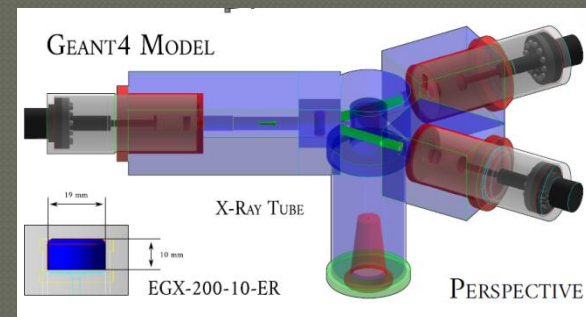
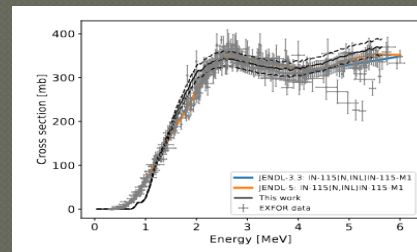
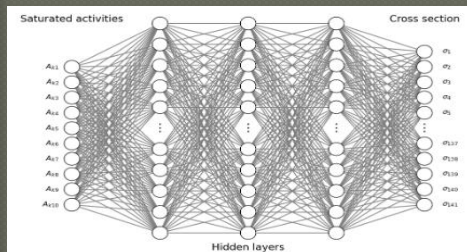
Experiments with photonuclear and neutron induced reactions

- Study of effective cross section and yield of photonuclear reactions
 - Methods for characterizing the photon beam
 - Collaboration with JINR, Dubna
- Measurement of cross section values for neutron induced reactions
 - Collaboration with European Commission, Joint Research Centre (JRC), Geel, Belgium



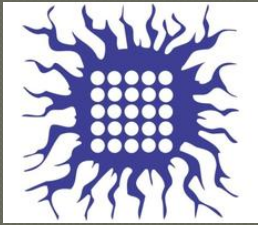
Machine learning techniques in Nuclear physics

- In collaboration with Technische Universität München, Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II), Garching, Germany
 - Associate partner on the project: "EvalSpek-ML" funded by the Bundesministerium für Bildung und Forschung BMBF
 - The use of artificial neural networks for the unfolding procedures in neutron activation measurements
- In collaboration with EC JRC Karlsruhe – the use of AI in gamma spectroscopy and analysis of nuclear materials
 - One PhD student was funded twice by ENEN+ programme to work at JRC Karlsruhe for 3 + 6 months
 - Hybrid K-edge study through Geant4 simulations ongoing



VINČA Institute of Nuclear Sciences

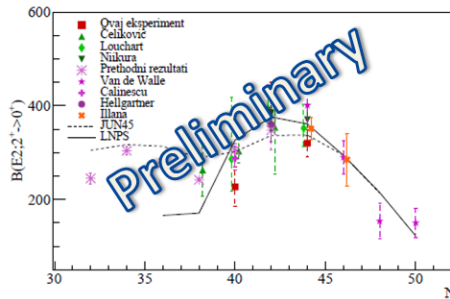




Laboratory for nuclear and plasma physics

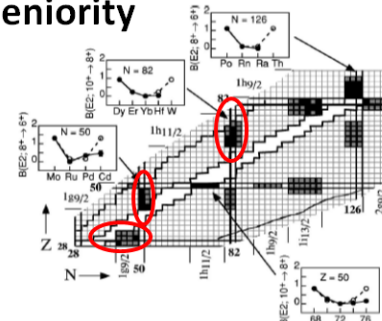
Nuclear Structure far from stability

- Islands of inversion $N=40$;
- Doubly magic nuclei: ^{78}Ni , ^{100}Sn ;
- Evolution of collectivity from $N=40$ toward $N=50$



- Collaboration: GANIL, INFN-LNL, GSI, IN2P3 Orsay

- Nuclei with (anomalous) good seniority



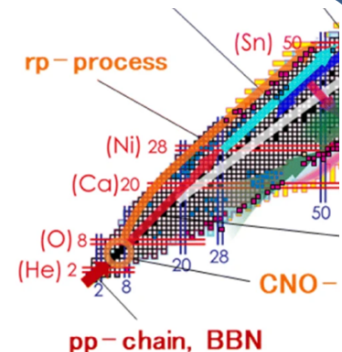
J. Ressler et al., PRC69_034317

- Collaboration with KTH and GANIL

- Theory: SM calculations supporting nuclear structure experiments
 - Level scheme, reduced transition probabilities
 - Particle-core coupling
- Monte Carlo simulations

Nuclear astrophysics

- Neutron deficient region
- Resonances in unbound nuclei
- Lifetimes of states relevant for astrophysics
- Collaboration: GANIL



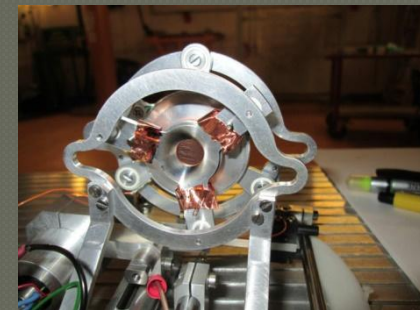


Laboratory for nuclear and plasma physics

- Measurement techniques:
 - Techniques related to prompt and delayed gamma spectroscopy
 - Lifetime measurement of ground and low-lying excited states
 - Experiments with the last generation γ -spectrometers (AGATA, ν -BALL)
- Experiments in nuclear facilities
 - Accelerator facilities : GANIL, INFN-LNL, GSI, IN2P3 Orsay...
 - Research reactors: ILL Grenoble, Budapest research reactor
- Staff: (2 + 1) permanent researchers, students at different stage at University



AGATA@GANIL, 2016, photo: E. Clément



Cologne plunger, for RDDS method

More than 5 research publications per year.



Applied nuclear physics activities

LABORATORY FOR NUCLEAR AND PLASMA PHYSICS

- Gamma spectrometry: radionuclides in the environment, sources, transport
- Metrology of radionuclides
- Direct activity measurements, sum-peak method
- Radon (different applications): e.g. climate change monitoring
 - Staff: 3 (+2) permanent researchers



DEPARTMENT FOR RADIATION AND ENVIRONMENTAL PROTECTION, SECTOR FOR RADIONUCLIDE TESTING

- Gamma spectrometry: radionuclides in the environment, sources, transport
- Metrology of radionuclides
- ^3H , ^7Be , ^{90}Sr
- Radon (different applications):
 - Staff: 4 permanent and much more staff and activities regarding dosimetry, radiation protection, nuclear energy, radiation and nuclear safety





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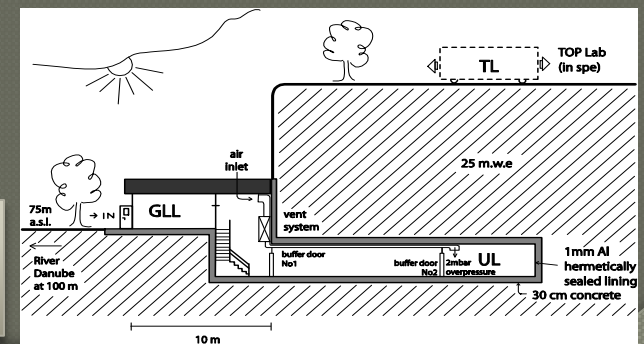


Low background laboratory for nuclear physics

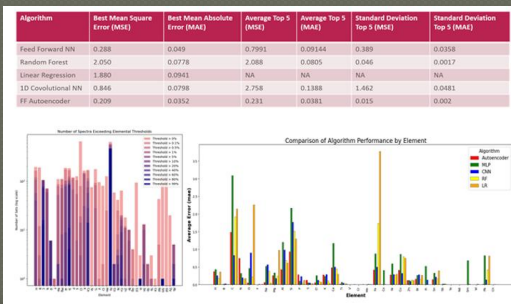
- Members: 9 researchers with PhD
- Research activities are mostly focused on obtaining the lowest radiation background for gamma spectroscopy performed in the Underground laboratory (UL), which is hermetically sealed and over-pressurized against radon intrusion (~ 10 Bq/m³) and aluminum shielded.
- Those activities are closely related to Comprehensive studies of background for high sensitive experiments, and studies like Radon activity and Cosmic ray flux intensity monitoring, (multivariate) analyzing, and simulating, then, Cosmic ray induced signatures in low energy detectors, Environmental radiation, cosmogenic radionuclides in air and soil.
- Working on those studies led to work being done in collaboration with external laboratories and collaborations, like:
 - Radon studies (IAEA RER9136: Reducing Public Exposure to Radon by Supporting the Implementation and Further Development of National Strategies)
 - Study of Muons within MICE experiment* RAL, UK (EuCARD-2)
 - Terrestrial and Space weather & climate studies (Georgia State University, Atlanta, USA).
- Most of the international collaboration work is done by studying nuclear reactions and gamma spectra, which also include development of significant number of MC simulations and Machine learning applications.

*MICE experiment is explained in more details in presentation
“Future coliders”, I.Bozovic

Around 5-10 research publications per year.



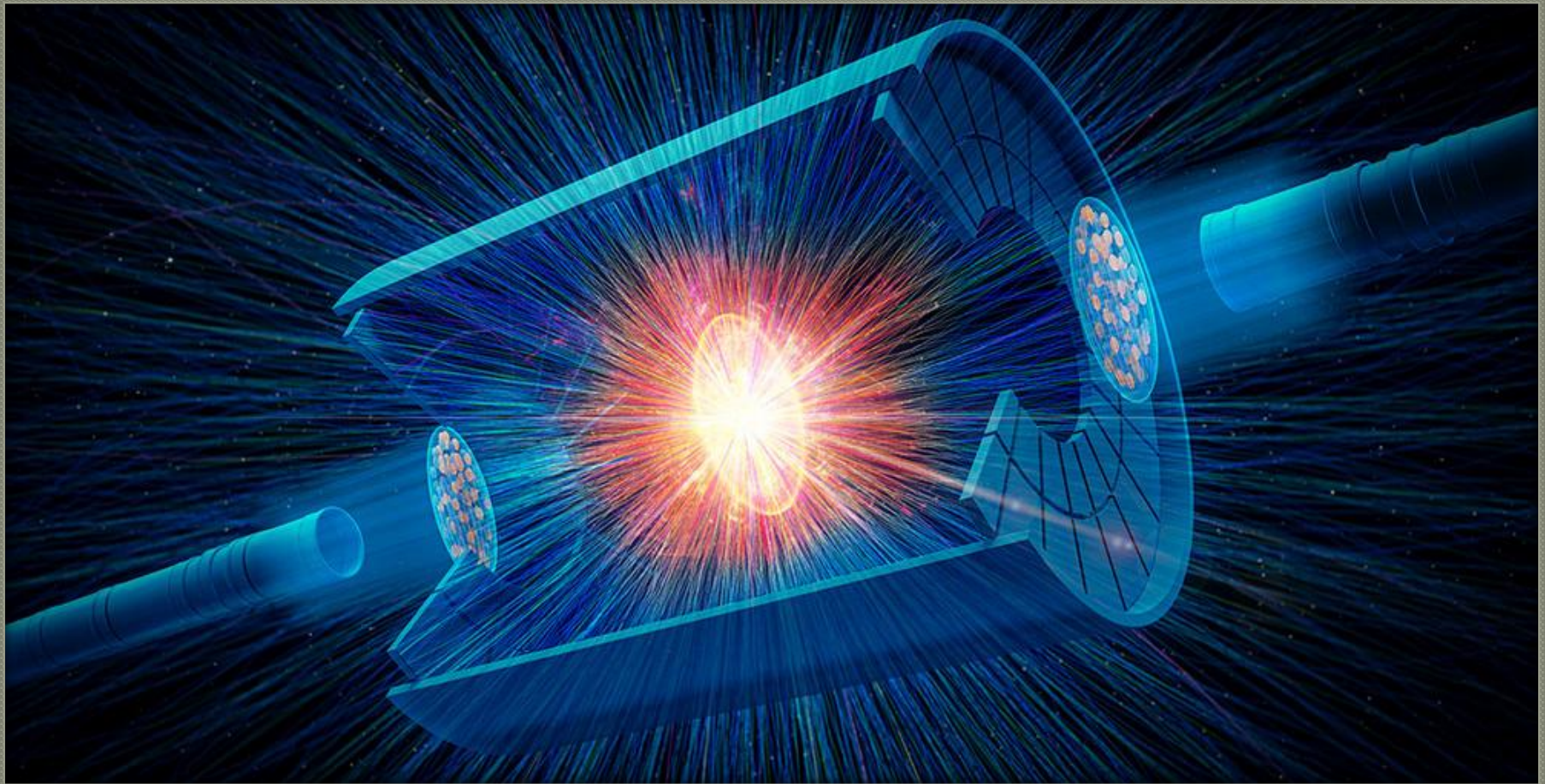
- Some of the research activities of the group are:
 - “Determination of elemental composition of the target using Prompt Gamma Activation Analysis” with colleagues from Research Neutron Source Heinz Maier-Leibnitz (FRM II), Technical University of Munich, within EvalSpek ML project funded by German Federal Ministry of Education and Research.
 - “Two-step gamma cascades (n,gamma) for determination of new gamma-ray transitions and new energy levels”, and “Photoactivation studies (gamma,xn)”, which deals with determination of cross section functions through various methods, determination of bremsstrahlung spectra with unfolding, and also investigation of contributing (γ ,pxn) reactions. These topics include collaborators, or facilities for measurements, also from other institutes like JRC, IJCLab, FRM-II, BNC, IMC and JINR (within JINR-Serbia cooperation projects supported by Ministry of Science, Technology and technical development of Republic of Serbia).
 - There is also notable participation in nu-Ball experiments at ALTO research platform in Orsay, France on subject like “Search for the fission shape isomer in ^{232}Th ”, or “Fission isomer experiment on ^{236}U ”. (EuCARD-2)
 - Machine learning and data analysis, to LISA “Lifetime measurements with Solid Active targets” which is being developed at GSI, Darmstadt, Germany, and under ERC grant.



Development of Machine learning application for determination of elemental composition of the target using Prompt gamma activation analysis

Conclusion

- There are numerous of activities related to nuclear physics in Serbia focusing on fundamental nuclear research topics and on applied nuclear physics investigations.
- Most of the fundamental research activities are performed in collaboration with well known external partners (CERN, GSI, JRC, GANIL, etc.)
- The new direction of Serbian Government is: starting of a nuclear programme – MoU for the development of the application of nuclear energy has been signed on 10th July 2024 between 5 different ministries and 20 universities, research institutes and energy production facilities.
- Nuclear Society of Serbia was established last year and it is the entity that will strongly support nuclear programme in Serbia.
- The main focus at the moment is on education in emerging nuclear technologies, reactor technology, nuclear engineering, SMRs etc. The development of new academic curricula in the area of nuclear engineering and reactor technologies is of a high demand and it will be jointly prepared by different faculties/universities and research institutes.
- Besides that, there is a strong need for education of young students in the area of fundamental nuclear research and for that we highly appreciate all international collaborations and partnerships that we already have and new ones that we are hoping to establish.
- **Becoming a member of NuPECC will strengthen the further development of nuclear physics in Serbia.**



Thank you for your attention!

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