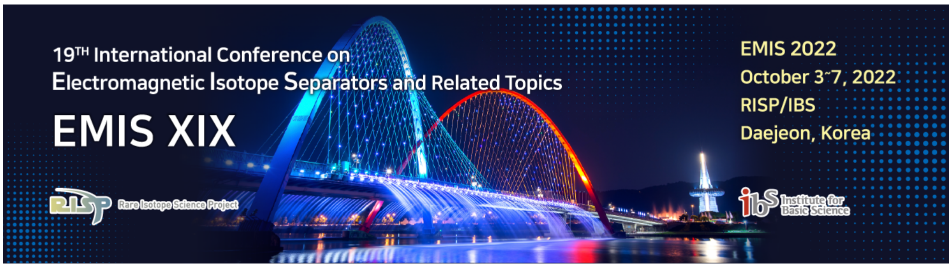

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Particle identification of VAMOS++ spectrometer data using several machine learning techniques

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The studies of low-lying excited states of the neutron-rich nuclei near the shell closures are one of the foremost topics of nuclear physics. The information of unstable, neutron-rich nuclei near N=126 magicity below 208Pb is crucial for understanding not only the nuclear structure of heavy nuclei but also the astrophysical r-process. However, the study of the south of 208Pb in the nuclear chart has been limited due to the difficulty of producing those nuclei.
We approached this region of interest using multi-nucleon transfer (MNT) reactions between 136Xe beam (7MeV/u) and 198Pt target. The experiment was performed at GANIL G1 hall. The VAMOS++ magnetic spectrometer [1] was set to grazing angle (40˚) with respect to the beam axis and used to identify projectile-like fragments (PLFs). The complementary target-like fragments'(TLFs) velocity vector was measured by the newly installed second arm set to the complementary angle (55˚). AGATA HPGe tracking array [2] with nominal configuration [3] measures the prompt gamma rays from the excited states of the produced nuclei. Additionally, the delayed gamma rays from TLFs were measured by EXOGAM HPGe clover array [4] located at the end of the second arm.
Unambiguous particle identification (PID) of PLFs from VAMOS++ data is the prerequisite for figuring out the origin of detected gamma rays in TLFs. Conventionally, multi-parameter analysis was carried out for PID due to the complex setup and reconstruction method. This method needs a lot of effort especially when ion energy has a broad range near a few MeV/u.
Therefore, we developed the new method using several machine learning techniques for PID. The supervised learning with the deep neural network (DNN) and boosted decision tree (BDT) was used to calculate the ion energy which is critical for mass and ion charge states calculation. The mass and ion charge state resolution show improved value compared to reported in the literature using the conventional analysis technique [5].
The atomic number (Z) identification was treated as multi-class classification problem with soft labels. We used semi-supervised learning to identify the nuclear charge state of a particle and to calculate its confidence. Compared to the conventional ΔE-E method, additional physical measurements such as velocity and mass can be used to deduce the nuclear charge state more accurately.

Primary authors: CHO, Youngju (SNU); KIM, Yunghee (Center for Exotic Nuclear Studies, IBS); Prof. CHOI, Seonho (SNU); Mr SON, Yonghyun (SNU); Dr ANDREEV, Andrey (Univ. of York); Dr JOHN, Philipp (TU Darmstadt); Mr UTEPOV, Ablaihan (GANIL); Dr ACKERMANN, Dieter (GANIL); Dr ALAHARI, Navin (GANIL); Dr BAE, Sunghan (IBS CENS); Dr BANIK, Ranabir (VECC); Dr BHATTACHARYA, Soumik (VECC); Dr BHATTACHARYYA, Sarmishtha (VECC); Dr CHAE, Kyungyuk (SKKU); Dr DE FRANCE, Gilles (GANIL); Dr DIDIERJEAN, Francois (IPHC); Dr DUDOUET, Jeremie (IP2I Lyon); Dr FOUGERES, Chloe (GANIL); Dr FREMONT, George (GANIL); Dr GOUPIL, Joan (GANIL); Dr GU, Gyoungmo (SKKU); Dr HA, Jeongsu (KU Leuven); Dr HIRAYAMA, Yoshikazu (KEK); Dr JEONG, Sunchan (KEK); Dr KIM, Chanhee (SKKU); Dr KIM, Minju (SKKU); Dr KIM, Sohyun (SKKU); Dr KORTEN, Wolfram (CEA); Dr LEMASSON, Antoine (GANIL); Dr MARINI, Paola (CENBG); Dr MIYATAKE, Hiroari (KEK); Dr MUKAI, Momo (RIKEN); Dr MUKHERJEE, Gopal (VECC); Dr NIWASE, Toshitaka (KEK); Dr PARK, Joochun (IBS CENS); Dr PEREZ VIDAL, Rosa Maria (INFN-LNL); Dr RAMOS, Diego (GANIL); Dr RECCHIA, Francesco (Univ. of Padova); Dr REJMUND, Maurycy (GANIL); Dr REZYNKINA, Kseniia (INFN-Padova); Dr ROSENBUSCH, Marco (RIKEN); Dr SCHURY, Peter (RIKEN); Dr THOMAS, Jean-Charle (GANIL); Dr TREASA, Deby (CENBG); Dr TSEKHANOVICH, Igor (CENBG); Dr WATANABE, Yutaka (KEK); Dr DE ANGELIS, Giacomo (INFN-LNL)

Presenter: CHO, Youngju (SNU)

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