Terzo Incontro Nazionale di Fisica Nucleare INFN2016

ID contributo: **31** Tipo: **Poster**

NEDA: detecting neutrons in experiments with exotic nuclei at SPES facility

martedì 15 novembre 2016 14:57 (2 minuti)

Summary

Exotic nuclei are expected to unveil new information on nuclear structure and new facilities for their production and study are being build worldwide. Production rates are however several order of magnitude smaller than the ones of stable nuclei. Consequently, the radiation detection arrays to be used in nuclear reaction experiments must be improved on the efficiency performance side. In reactions involving exotic nuclei beams, the neutron channel is very important, especially in the case of neutron rich nuclei to be produced at the SPES facility in construction at LNL. To increase the neutron detection efficiency, the new array NEDA was designed and is under development. The array is built on the replica of a single detector unit. With its relatively higher neutron multiplicity detection efficiency, NEDA will be used in forefront experiments at European accelerator facilities such as the soon to be SPES at LNL. The main characteristics of the prototype unit were evaluated through off-line analysis of the sampled signals from a 252Cf n-gamma source, with particular attention to the n-gamma discrimination power and timing. In this contribution, the application of a Neural Network concept for an on-line neutron-gamma separation process is considered.

The chart of nuclides maps all the nuclei that are known or that are predicted to exist by nuclear models. In nature only about 250 types of nuclides are available, however theories predict the existence of more than 7000 nuclei. New nuclides can be artificially produced and so far it was possible to synthesize about 3000 new species. Nuclei far from the line of stability are often called exotic nuclei as they possess structural properties that do not follow the systematics of stable nuclei. Because of this, in the last few years the scientific community found a rising interest toward the study of exotic nuclei whose useful results are expected to strengthen the actual nuclear models and to find ways to produce new isotopes. To produce exotic nuclei, nuclear reactions with very low cross sections, of the order of few mb , are exploited. These reactions often involve, as projectile, radioactive ion beams whose intensities are orders of magnitude lower than stable standard ion beams. Often, so called compound nuclei are formed by the fusion of the projectile and target nuclei. They are highly unstable and decay instantly emitting gamma-rays, charged particles and neutrons, in a process called evaporation. Fission of the nucleus is also possible. By detecting simultaneously light particles and γ -rays, it is possible to extract structural features of an excited nucleus. Arrays of high purity Germanium detectors (HPGe) are the most efficient tool for gamma-ray spectroscopy measurements. However, Germanium detectors alone don't allow the identification of the light particles that precede the discrete gamma-ray emission. For this purpose they are coupled with ancillary detectors able to detect evaporated particles. With stable heavy ions beams, proton rich nuclei, produced in fusion-evaporation reactions induced by heavy ions, can be identified only through the selection of the decay channels in which the emission of multiple neutrons is observed. Cross sections of these channels are typically low (orders of tens of μb), thus a clear and efficient identification of the number of neutrons emitted is mandatory.

Neutron detection is not a easy task. As neutrons carry no charge, they interact with matter only through nuclear force with relatively low cross sections that strongly depend on the energy of the neutron itself. Detectors based on organic liquid scintillator coupled with a photomultiplier tube (PMT) are widely used in neutron detection. In order to design an efficient detector array, various factors should be taken into account. Dimensions should be sufficient for the particle to lose all its energy inside the hit detector liquid without interacting with the surrounding detectors. At the same time dimensions of the detector should be limited in order to avoid scintillation light attenuation through the medium. Another problem with scintillation detectors is that they are also sensible to other kinds of radiation, such as gamma-rays and charged particles, and it is mandatory to develop algorithms that are capable of discriminating the kind of radiation that hits the detector. As different particles are characterized by different signal shapes, algorithms that exploits pulse shape discrimination are often used to fulfil this task.

A new generation of neutron detector array, which is in the process of production, is NEDA (NEutron Detector Array). It will replace Neutron Wall and will be used in experiments with stable and radioactive beams at

the European accelerator facilities such as SPES at the LNL.
The use of the NEDA array, coupled with other particle and gamma detector arrays, in experiments with neutron-rich and proton-rich nuclei will allow the investigation of regions in the chart of the nuclides whose properties are predicted only by theoretical models. For example, the dependence of the effective interaction between the nucleons of exotic N/Z ratios could be investigated. Shell structure also changes as function of neutron excess and this evolution has consequences on the ground state properties (spin, parity, electromagnetic moments). Research of new magic numbers, predicted by new models, will be also performed. The collective motions of the nucleus could also be probed, with attention on particular nucleus structures like neutron halo and neutron skin.
NEDA array will be composed by 300 scintillation detectors and was designed to achieve the highest possible neutron detection efficiency, excellent discrimination of neutron and gamma-rays and small neutron-scattering probability. Particularly, as the array will be involved in experiments with radioactive ions beams it will work in environment with high gamma-ray background, so it should grant the highest possible n-gamma discrimination efficiency.
The NEDA detector unit consists in a hexagonal based prismatic cell. The cell is filled with a xilene based liquid scintillator and it is coupled to a PMT through a glass window. After the prototype was assembled an experiment was designed and performed in order to evaluate the main characteristics of the detector with particular attention in testing the neutron-gamma discrimination power. As comparison, the same analysis was performed with the same experimental set-up for a second detector which consisted in a 5"x5"cylindrical cell (the biggest that can be found on-shelf) coupled to the same PMT used for the prototype. Signals coming from a 252Cf radioactive source, which emits both neutrons and gamma, were sampled and analysed through a code specifically developed that implements various algorithms used in pulse-shape analysis.
As first analysis the photo-electron yield (number of photo-electron measured at the photo-cathode of the PMT for unit of released energy) was measured. The obtained value shows that the detector has a good yield that grants good detection efficiencies at low energies. The results were compatible with the cylindrical detector.
Then, an average of the shape of the sampled signal was performed. The average of the signals coming from a 137Cs source (gamma source) and the average of the signals from the 252Cf source (neutron-gamma source). As expected the two signals differs in the tail and this allow the use of pulse-shape discrimination algorithms in order to identify neutrons and gamma.
Using the charge comparison (CC) and the integrated rise time (IRT) algorithms, the neutron-gamma discrimination power was measured at various energies. The figure of merit (FOM) has been chosen as quantitative parameter for the discrimination quality. Both discrimination methods gave the same results for the FOM, showing that the performed analysis is consistent and that there is no advantage in choosing one method over the other for n-gamma discrimination.
FOM values obtained with the CC method were compared with the one obtained for the 5"x5" cell detector. Discrimination performances for this detector appear to be better by a factor 2. The cause of this discrepancy lays in the differences in geometry and dimension of the two detectors. Finally, a time of flight analysis was performed to achieve better n-gamma discrimination. It is shown that coupling the TOF and CC methods lowers the value of the neutron-gamma discrimination energy threshold from ~1.7 MeV to ~0.7 MeV. This is a very important achievement since the maximum in the neutron energy spectra, for the reactions of interest for the NEDA array, is usually located around 1MeV.
The presented analysis allowed to characterize the prototype cell that will be employed in the NEDA array in terms of photo-electron yield, timing and pulse shape analysis and was used by NEDA collaboration to better understand the properties of the prototype and to improve the detector.
The development of Neural Network algorithms to achieve an automated and improved n-gamma discrimination is under evaluation and preliminary work is in progress in order to choose the best approach strategy.

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Classifica Sessioni: Posters