In-beam commissioning of the NEBULA-Plus neutron array

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The NEBULA-Plus array is a 90-element two-wall large area plastic scintillator array[1)] designed to be coupled to the NEBULA fast neutron array[3)] to augment the neutron detection efficiency for SAMURAI-based experiments. As described in an earlier progress report,[4)] NEBULA-Plus was installed at SAMURAI, along with the FASTER digital electronics and acquisition system,[2)] in Summer-Autumn 2022. Subsequently, extensive testing was undertaken using γ-ray sources and cosmic rays, whereby the latter were also employed to test the coupling of NEBULA-Plus and NEBULA, including that FASTER and SAMURAI data acquisition systems (DAQs) and the off-line merging of the data from the two systems.

The in-beam commissioning of NEBULA-Plus was performed in April 2024 using a quasi-mono-energetic beam of neutrons of around 240 MeV produced using the well-known ^{7}Li(p,n) reaction with a beam of protons produced from a 250 MeV/nucleon ^{18}O beam using the BigRIPS separator. The principle objectives of the commissioning were: a) to determine the NEBULA-Plus single-neutron detection efficiency, b) test and optimize the FASTER electronics and DAQ, including the coupling with the SAMURAI common dead-time DAQ (Fig. 1), under realistic experimental conditions, and c) test the count-rate capabilities of FASTER. Both b) and c) were also tested using a relatively high intensity ^{10}Be secondary beam (up to 1×10^6 pps).

The two DAQs have their clocks synchronized but are independent and write their data to separate files. FASTER is started and stopped using the SAMURAI DAQ, from which an initial time can be inferred. The NEBULA-Plus trigger, corresponding to at least one scintillator bar being hit, is generated (with a $\sim$500 ns delay) and sent to the SAMURAI DAQ to be included in the main trigger. The SAMURAI DAQ accepted trigger is subsequently sent to a channel in FASTER, which provides for an absolute time stamp. The data are merged offline based on this time stamp. Note that to verify that the merge is performed correctly, both DAQs encode the signals from the SAMURAI SBT thin plastic detectors located at F13. The SBT signals, as for NEBULA, provide the start for the neutron time-of-flight measurement.

An example of the data acquired using the 240 MeV neutrons from the ^{7}Li(p,n) reaction are shown in Fig. 2. The events shown were selected after application of a threshold (6 MeVee) in the charge registered by the scintillator bar. A narrow peak corresponding to the quasi-mono-energetic neutrons is clearly apparent. Further detailed analysis is underway to provide a determination of the neutron detection efficiency, which will be compared with simulations based on the known differential angular distribution for the ^{7}Li(p,n) reaction.

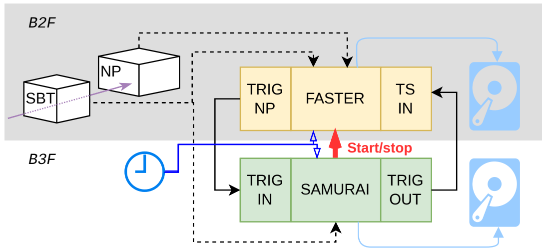

Fig. 1. Schematic representation of the coupling of the FASTER and SAMURAI data acquisition systems, where NP is NEBULA-Plus and SBT is the SAMURAI thin plastic start detectors.

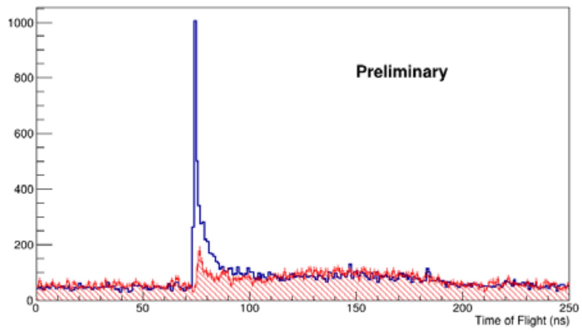

Fig. 2. Neutron time of flight for a central scintillator bar in the first layer of the first wall of NEBULA-Plus. Blue: data acquired with the ^{7}Li target. Red: data acquired with an empty target.

References
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2) http://faster.in2p3.fr/.
3) T. Nakamura, Y. Kondo, Nucl. Instrum. Methods Phys. Res. B **376**, 156–161 (2016).
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