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Study of in-beam performance of Hyperball-J Ge detector units with the current beam structures at the K1.1BR beam line

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Abstract

In-beam testing of two Ge detector units of the Hyperball-J array for the up coming E13 experiment at the K1.1Br beam line is proposed. In particular, the Ge detector response to the current beam condition with a micro structure will be studied. The experiment will be organized in two phases. In the first phase, a signal through put (live time) of the detector unit will be measured with a 200-Hz pulser under various conditions and counting rates. In the second phase, an energy and time resolution of the Ge detector during the beam on/off cycle will be measured using the $^{10}\mathrm{B}(\pi, \pi'\gamma)^{10}\mathrm{B}^*$ reaction and LSO pulsers. At the same time, performance of background-suppressing PWO counters will be studied. Pion beams of ∼1 GeV/c with a minimum intensity of 500k/spill is required. Totally, 72 (+6) hours of beam time are requested.

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I. INTRODUCTION

Hyperball-J, a new γ-ray spectrometer dedicated to an ultra-high precision spectroscopy of hypernuclei, will be the main experimental apparatus for the E13 experiment, of which initial phase is anticipated to be carried out at the K1.8 beam line during the fall-winter beam time in FY2012. This spectrometer is an array of 32 high-purity Germanium (HPGe) detectors, each of which is surrounded by a scintillation counter for back ground suppression. Extreme experimental conditions with an intense beam to be available at J-PARC required construction of the new array. In particular, a sever radiation damage and a high energy deposit rate on a Ge detector demanded a development of new detector units. The first factor resulted in replacing the conventional LN2 cooling of a Ge crystal by mechanical cooling with a compact pulse tube refrigerator. This scheme has succeeded in lowering the crystal temperature down to 70 K, which is 20 K lower than the LN2 cooling. According to the experimental study, degradation in energy resolution of a radiation damaged Ge detector depends sensitively on its crystal temperature. 70 K realized in our detector unit is expected to increase radiation hardness compared at 90 K. The second point, a high energy deposit rate, led to the use of PWO crystals for fast suppression as an alternative to the conventionally used BGO scintillators. An order of magnitude smaller light yield of PWO crystals than that of BGO must have been overcome. Combination of high quality doped PWO crystals, use of highly reflective wrapping materials, and a cooling of PWO crystals has proven effective in achieving a comparable suppression quality with the BGO crystals. Lastly, a new readout scheme based on digital signal processing with an interface amplifier is being developed jointly with Argonne National Laboratory, U.S.A. Recently a prototype interface amplifier, a key component for the digital readout system for a low-gain and reset-type preamplifier for our Ge detector, is designed.

In order to monitor difference in the Ge detector response between spill on and off, a LSO pulser is attached to each Ge detector. A LSO pulser detects β particle following the β decay of ^{167}Lu in the LSO crystal. The β-γ coincidence between the LSO counter and the Ge detector allows for a clean spectrum of reference γ-ray peaks.

At the E13 experiment scheduled in FY2012, the expected beam intensity is 500k/spill when kaons and pions are combined. The slow-extracted beam at present, however, shows a comb-like structure in the intensity as a function of time within a beam spill cycle as evident in Fig.1. An averaged beam rate is ∼1 MHz, while the instantaneous rate could be an order of magnitude higher. Therefore, Ge detectors will be exposed to much larger instantaneous beam intensity than the 500k/spill value which is averaged over the spill-on duration. Because the success of the up coming E13 experiment depends crucially on the operation of Hyperball-J and thus of its detector units, it is imperative to test these units under the current beam conditions, which would be the closest to the experimental conditions of E13.

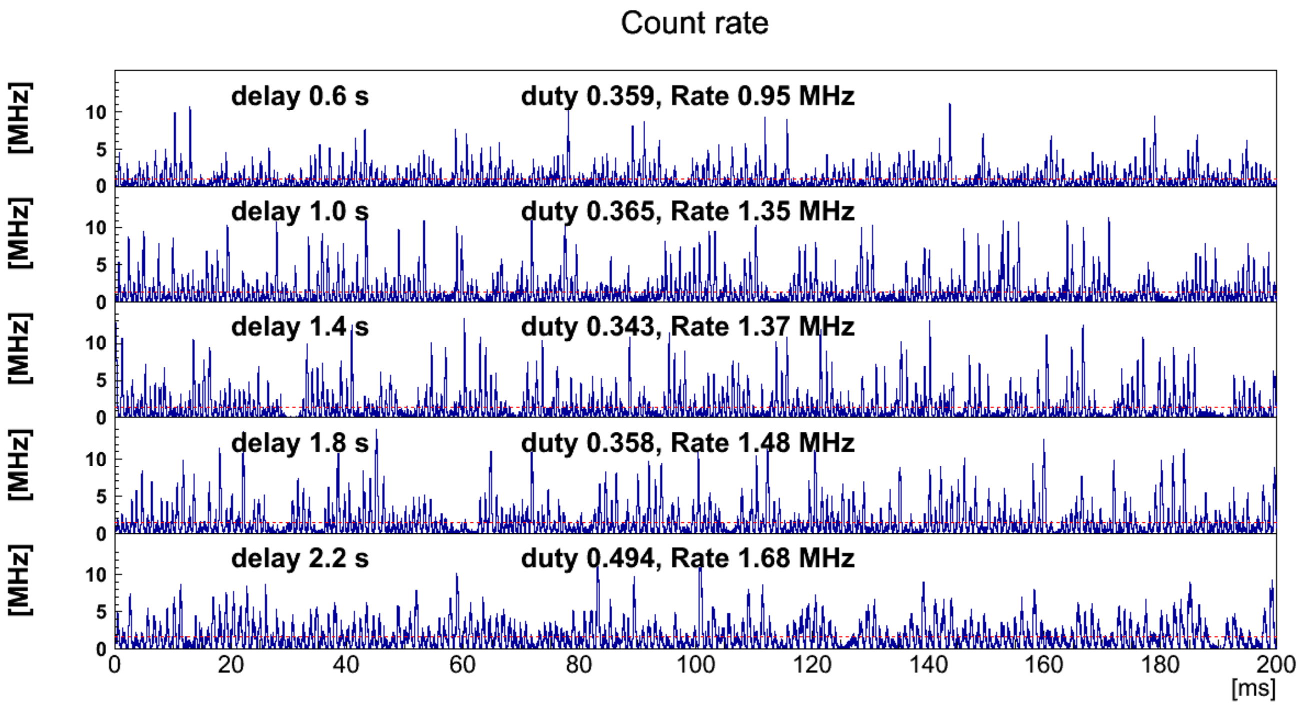

FIG. 1: A typical beam count profile taken during the E19 experiment in February, 2012. The beam-on duration was 2.2 s in the 6 s spill cycle. Five snap shots of 200 ms each over the 2.2 s are shown. The comb-like micro structures of the beam are evident through the entire beam-on period.

II. EXPERIMENTAL OBJECTIVES

In this test experiment, two detector sets, each consisting of a Ge detector with a pulse tube refrigerator, PWO counter, and a LSO pulser, will be placed near a target. Since there are two types of Ge detectors produced by two different manufactures, each type needs to be tested. Main objectives are listed in the following.

(1) Study of Ge detector response under the in-beam condition:

- Measurement of signal through put (live time) with a pulser
- Measurement of energy and time resolution during a beam on/off cycle

(2) Study of PWO counter response under the in-beam condition:

- Measurement of suppression performance

(3) Checking of operation of a LSO pulser

III. EXPERIMENTAL METHODS AND THE SET UP

The experiment is divided into two stages. In the first stage, through put of Ge detectors will be measured with various conditions. In the second stage, the energy and time resolution together with the PWO suppression performance will be measured. The experimental setup is schematically shown in Fig.2. Two Ge detector + PWO counter + LSO pulser units (Fig.3), each mounted on a lifter, will be installed on each side of the beam.

In the first stage, a pulser signal at 200 Hz is fed through the test inputs to the Ge detectors. Through put of this pulser signal will be measured for the ∼1 GeV/c pion beam intensity of 500k/spill. A trigger will be generated by a pulser, and the background will be generated by any reactions of the beam with the target. Single counting rates, detector reset rates, and pile up rates will be recorded by a scaler module. At a fixed detector-target distance, the Ge detectors will be placed at three angles with respect to the beam axis as defined in Fig.2, namely at 45°, 90°, and -45°. This measurement is necessary to see the dependence of the Ge singles rate on the detector angle due to the anisotropic scattering of beam particles by the target. At the 90° detector position, distance between the target and the Ge detector will be varied in order to see a rate dependence of the through put. Five distances will be tried. In addition, through put for the 90° configuration at one target-detector distance will be measured for 200k/spill and 750k/spill beam intensity.

In the second stage, an energy and time resolution for the 718-keV γ ray from ^{10}B$(\pi, \pi'\gamma)^{10}$B* will be measured. The ^{10}B$(\pi, \pi'\gamma)^{10}$B* reaction will be selected by an anti-coincidence between a beam profile counter (BPC) and a beam veto counter (BVC), which rejects beam particles simply passing through the target. The detector response for the beam on/off cycle will be simultaneously monitored with LSO counters placed as in Fig.2. The average rate of a LSO pulser is around 10 Hz, and this rate is too low to accumulate 1000 photoelectric peak count. Therefore, four additional LSO pulsers will be placed on top of the aluminum end cap of the Ge detector. Timing as well as energy information of the PWO counters will also be taken, with which the suppression performance can be evaluated by an off-line analysis.

IV. REQUESTED BEAM TIME

In total, 72 hours (+ 6) is requested for the present experiment. The requested beam time was estimated according to the following run plan.

- If there is no access to the experimental area before the beam time, a time for the installation of the set up is necessary. This would be 6 hours.
- Beam counter tunings with beams: 3 h
- Tuning and optimization of a trigger: 2 h
- Various checks and tunings of the detector and electronics prior to data taking: 7 h
- Phase1: Through put study with pulser signals: 24 h
- Phase2: Energy and time resolution measurements: 36 h

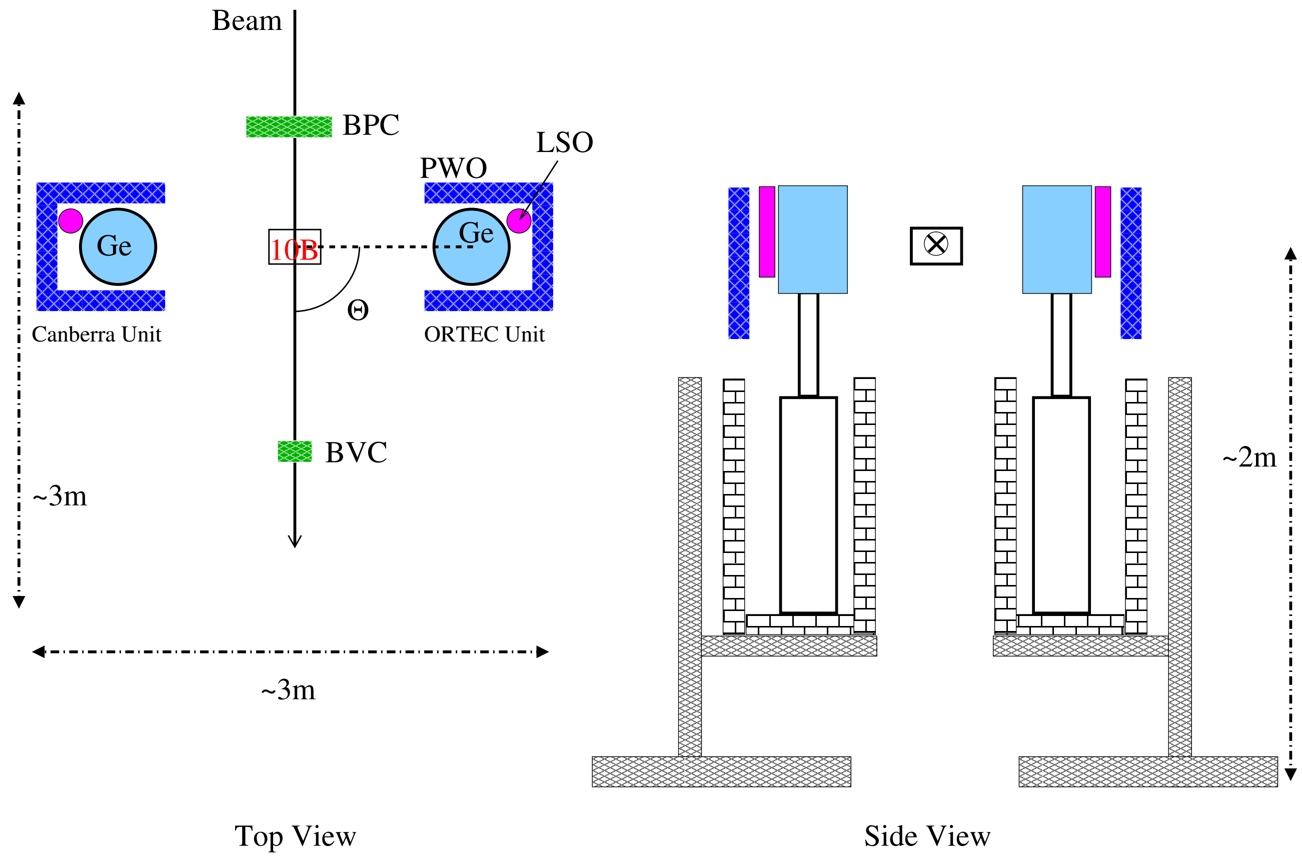

FIG. 2: A schematic view of an experimental setup. Top view on the left and side view on the right. From the up stream, a beam profile counter (BPC), a ^{10}B target, Ge+PWO+LSO detector units for ORTEC and Canberra Ge detector each, and a beam veto counter (BVC).

V. MISCELLANEOUS ISSUES

The requested experimental area is 3 m X 3 m. Two portable (manual) folk lifters, to which the Ge detector units will be mounted, are requested. Two electronics racks for NIM bins and VME crates and an AVR power supply of ∼5k AV are also requested. In order to cool pulse tube refrigerator compressor, a water chiller will be used. This chiller is self-contained and needs no external water supply. We request a permission for the use in the experimental area.

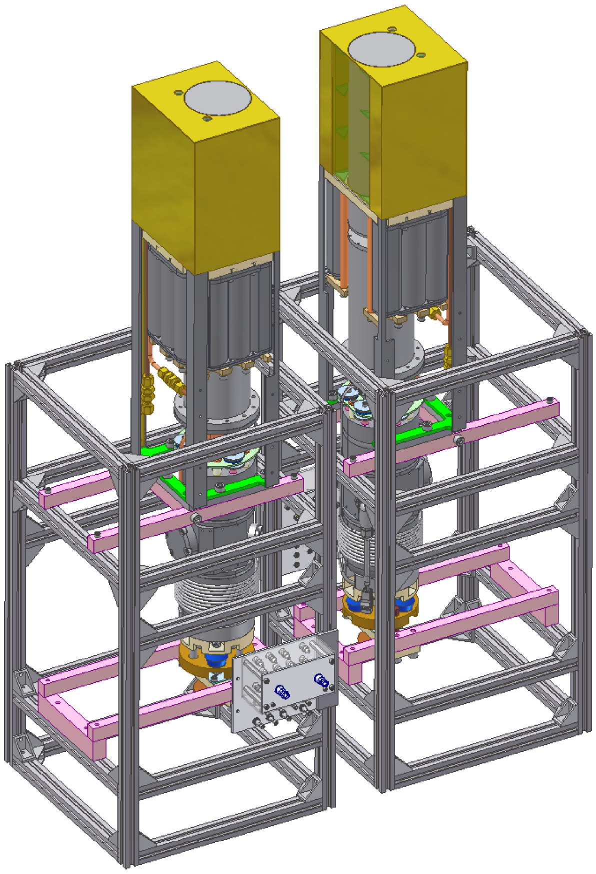

FIG. 3: The Hyperball-J Ge units to be mounted on portable fork lifters. The closest distance between the two detectors is 9 cm (detector center to center).