PROCEEDINGS OF SCIENCE

Detector calibration in the sub-MeV range in JUNO

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The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose physics underground experiment in southern China. Its central detector consists of a 20-kton liquid scintillator and 17,612 20-inch photomultiplier tubes. A dedicated multi-messenger trigger system has been developed to maximize JUNO's potential for astrophysics events, lowering the data-taking threshold to around 20 keV. The currently existing calibration sources for JUNO are envisioned to be deployed to calibrate the MeV energy range, and hence new radioactive sources as well as calibration strategy are necessary to calibrate the sub-MeV range (from O(10) to O(100) keV). For this purpose, Radium-226 (186 keV gamma-ray) and Americium-241 (59.5 keV gamma-ray) are considered as primary radioactive calibration sources. This proceedings paper describes the calibration feasibility in this very low-energy range including impacts on the calibration quality due to the source apparatus geometry, separation from Carbon-14 backgrounds using the JUNO detector simulation tool, and also introduces the status of the low-energy calibration source preparation.

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1. Introduction

The JUNO detector [1] will be the world's largest underground liquid scintillator detector, currently under construction in Jiangmen, China. The detector is composed of a 20-kton liquid scintillator and 17,612 20-inch photomultiplier tubes (PMTs). It will be a multi-purpose detector, aiming to determine the neutrino mass ordering as its primary experimental goal by measuring the energy spectrum of reactor antineutrinos and to study atmospheric/geo/solar neutrinos, etc.

Besides the aforementioned physics goals, astrophysical neutrinos can be also observed in the JUNO detector. To improve such astrophysics potentials in JUNO, a dedicated event trigger system, named multi-messenger (MM) trigger, has been developed [2–4]. This trigger system not only counts the number of PMT hits within a certain timing window but also takes into account their timing and space information to distinguish events caused by charged particles and events caused by the PMT dark noise fluctuation. With this new trigger scheme, the detector trigger threshold in this data stream can be lowered down to ~20 keV electron energy as shown in Figure 1.

However, the existing calibration sources in JUNO, most of which are described in [5], have been developed to calibrate events in the MeV range. To take full advantage of the newly explored energy range in JUNO by the MM trigger system, we need to develop dedicated calibration sources for this very low-energy region. This proceedings paper introduces new radioactive calibration sources and describes the expected calibration performance as well as the status of the source preparation.

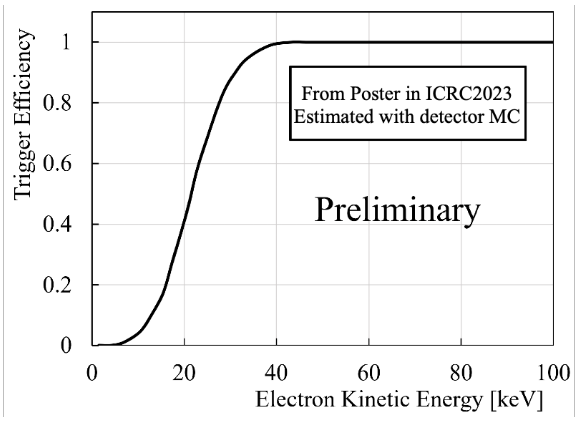

Figure 1: The trigger efficiency curve as a function of the electron kinetic energy. Taken from [4].

2. Calibration in the sub-MeV Energy Range

2.1 Radioactive Sources

The following two radioactive sources are currently considered for detector calibration in the sub-MeV energy range:

- ^{241}Am: After its α-decay, a 59.5 keV γ-ray is emitted. The production of the ^{241}Am source under development.

- ^{226}Ra: This is also an α-decay radioactive nuclide, and 186 keV γ-ray is emitted after the α-decay. Daughter isotopes from ^{226}Ra also emit various energy γ-rays, such as 352, 295, 242, 53.2 keV γ-rays from ^{214}Pb, 46.5 keV γ-ray from ^{210}Pb, and so on. The status of the ^{226}Ra source preparation is described in Section 3.

2.2 Feasibility Study

The feasibility of the calibration using the above two sources has been studied. Using the JUNO simulation [6], potential biases in the energy calibration have been investigated. The following two items are addressed in this study:

- γ-ray energy loss in the non-liquid scintillator volume: The radioactive source is planned to be packed into a stainless steel capsule and the stainless steel capsule is also further encapsulated into a PTFE container when it is deployed into the JUNO detector. Although mono-energetic γ-rays are emitted from those radioactive sources, a part of the energy may be lost before coming out from the calibration source capsule. The effect has been estimated using the detector simulation including the source capsule geometry as it is discussed in [5] for other radioactive sources.
- Contamination of ^{14}C, intrinsic radioactivity in the liquid scintillator: In this sub-MeV energy range, β-decays from ^{14}C (Q-value is ~156 keV) is expected to dominate the event rate. The abundance of ^{14}C is expected to be 10^{-17} g/g considering the past achievements in the Borexino experiment [7, 8], and its event rate will reach ~ 40 kHz in the 20-kton volume. Therefore, there will be a non-negligible amount of the events caused by its β-decays. To remove the influence from ^{14}C, vertex position cut has been applied to the simulated calibration source events as well as ^{14}C events, which are uniformly distributed in the liquid scintillator volume. By selecting events within 1.2 m from the source location, the amount of the ^{14}C events can be reduced to $\sim 5 \times 10^{-4}$ of the original amount. Furthermore, in the real experimental condition, the data without any calibration sources inside the detector will be handled as "source-off"/"^{14}C only" samples, and it can be used for the statistical subtraction of the observed energy spectrum to further eliminate the influence by ^{14}C.

The expected energy calibration bias has been evaluated by comparing the peak position of the energy spectrum in the calibration plus ^{14}C mixed sample and pure γ-ray events without the source geometry. Figure 2 shows the estimated bias for various calibration source candidates, and the bias has been evaluated to be less than 1%.

3. Radium Source Preparation

We have packed ^{226}Ra-infused particulates, which were provided by the domestic researcher and have multiple pores on their surface, into our calibration source capsule, and measured the radioactivity of ^{226}Ra using the germanium detector at Shanghai Jiao Tong University. Figure 3 shows the observed γ-ray spectrum measured with the germanium detector, and it confirms the clear peaks at expected energy ranges from the ^{226}Ra source. Multiple source capsules, whose radioactivity ranges from ~100 to ~1000 Bq, have been prepared such that the calibration event rate can be adjusted according to the detector trigger and data transfer bandwidth.

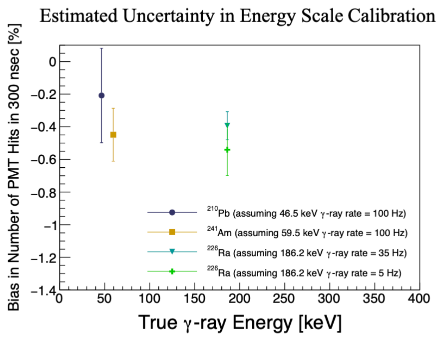

Figure 2: Potential bias in the energy calibration estimated with the JUNO detector simulation. As discussed in Section 3, multiple ^{226}Ra sources have been prepared with different radioactivity, and therefore the bias in the ^{226}Ra calibration has been evaluated based on multiple radioactivity scenario.

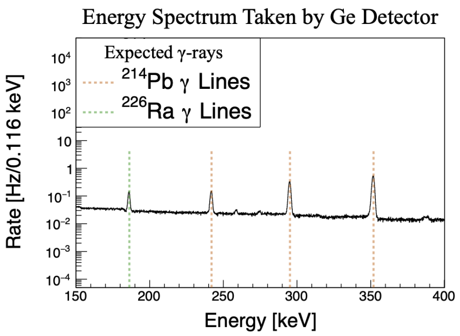

Figure 3: The obtained γ-ray energy spectrum from the ^{226}Ra-infused source particulates by the germanium detector at Shanghai Jiao Tong University. The vertical dashed lines denote the expected γ-ray energies from ^{226}Ra and ^{214}Pb.

4. Summary

To enable the physics analysis in the sub-MeV energy range explored by the newly developed trigger system, ^{241}Am and ^{226}Ra sources are considered as the calibration sources. The impacts on the energy calibration by γ-ray shielding caused by the source geometry and ^{14}C backgrounds have been estimated to be $\sim$1%. As for the status of the source preparation, the ^{226}Ra source is now ready to be installed into the JUNO detector.

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References

[1] A. Abusleme *et al.* (JUNO Collaboration), Prog. Part. Nucl. Phys. 123, 103927 (2022).

[2] Z. Ye *et al.*, Chinese Phys. Lett., 38, 111401 (2021).

[3] Z. Sun *et al.*, Maximizing the Astrophysical Potentials of JUNO with the Multi-messenger Trigger System, Poster in Neutrino Conference 2022 (2022).

[4] I. Morton-Blake *et al.*, Extending JUNO's Astrophysical Reach with a Low-Energy Multi-Messenger Trigger System, Poster in ICRC Conference 2023 (2023).

[5] A. Abusleme *et al.* (JUNO Collaboration), J. High Energ. Phys. 2021, 4 (2021).

[6] T. Lin *et al.*, Eur. Phys. J. C 83, 382 (2023).

[7] G. Alimonti *et al.* (Borexino Collaboration), Phys. Lett. B. 422, 349 (1998).

[8] G. Bellini *et al.* (Borexino Collaboration), Nature 512, 383 (2014).