Evaluation of neutron capture efficiency with Neural Network in SK-Gd

Y.Kanemura
ICRR Univ. Tokyo

Abstract

SK-Gd experiment had been started since July 2020, and the gadolinium(Gd) concentration was increased from 0.01%(called SK-VI) to 0.03%(called SK-VII) on July 2022. We could achieve increasing sensitivity of Super-Kamiokande(SK) to anti-electron neutrino by detecting total 8MeV gamma from Gd neutron capture.

In addition, we need an algorithm that could effectively select the neutron capture events and reject the BG ones.

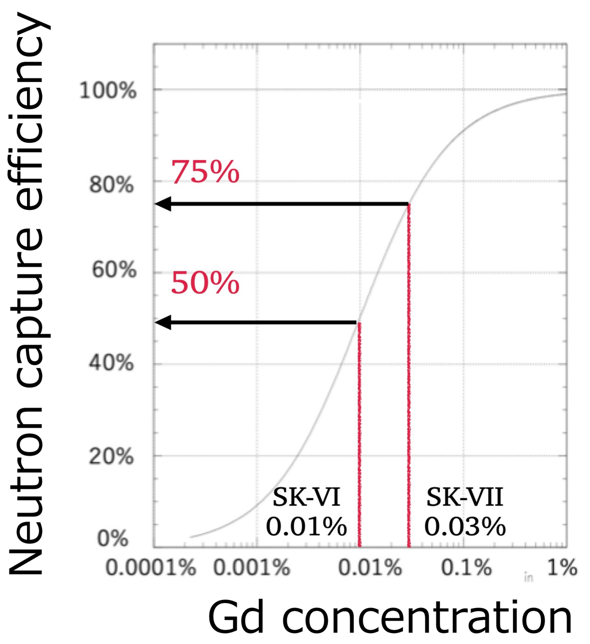
In this study, I evaluated the neutron capture efficiency in both SK-VI and SK-VII using neural network, and obtained higher capture efficiency than the conventional method while maintaining low BG contamination.

1. Introduction and Objective

- Gadolinium sulfate Octa-hydrate was loaded in SK on Jul.2020 for increasing detection efficiency of IBD.

$$\overline{\nu_e} + p \rightarrow e^+(prompt) + n$$

$$^{Z}Gd + n \rightarrow ^{Z}Gd^* \rightarrow ^{Z}Gd + \gamma(delayed)$$

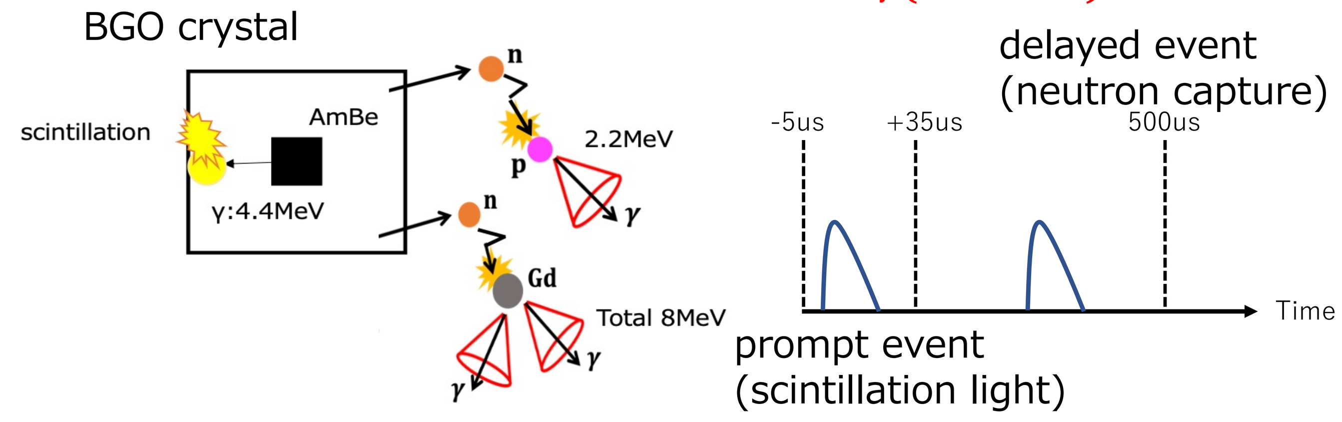


- Neutron tagging efficiency
  = Neutron capture efficiency
  ×detect efficiency

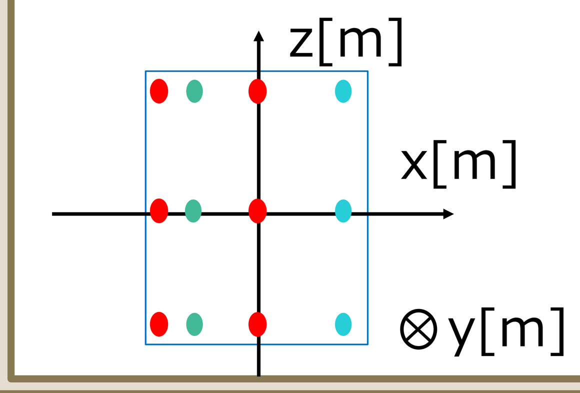
→An Algorithm that could effectively **select the neutron capture events and reject the BG events!**

2. Neutron data taking with AmBe source

◎ **^{241}Am-^{9}Be source:** $^{9}Be + \alpha(\text{from}^{241}\text{Am}) \rightarrow ^{12}C^* + \gamma(4.4MeV) + n$



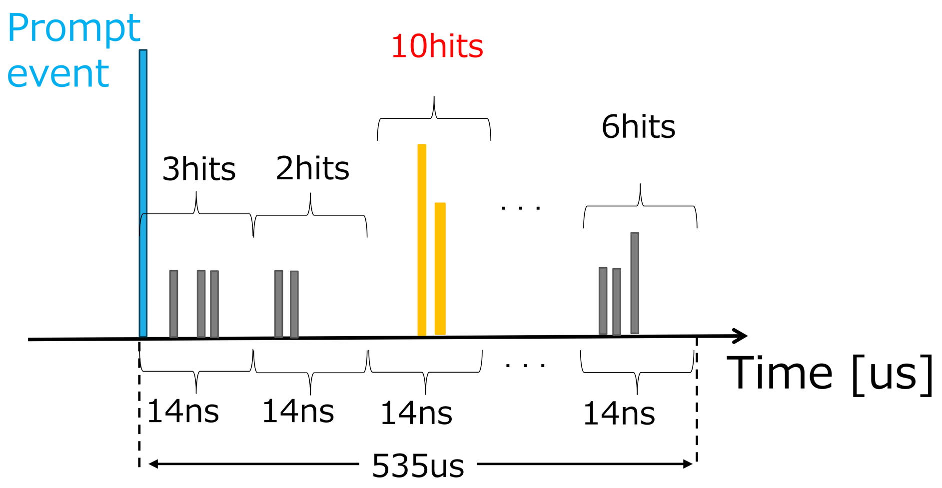
◎ **The details of the calibration**



- **Date:** Jan.2021(SK-VI)
  Jul.2023(SK-VII)
- **Position:**
  - ● Both in SK-VI and SK-VII
  - ● Only in SK-VII
  - ● Only in SK-VI

3. Neural Network(NN): TMVA (One of the ROOT libraries)

(1) Calculate the number of PMT hits



NHits: The number of PMT hit in 14nsec.

The events NHits ≥7hits are selected as neutron capture candidates!

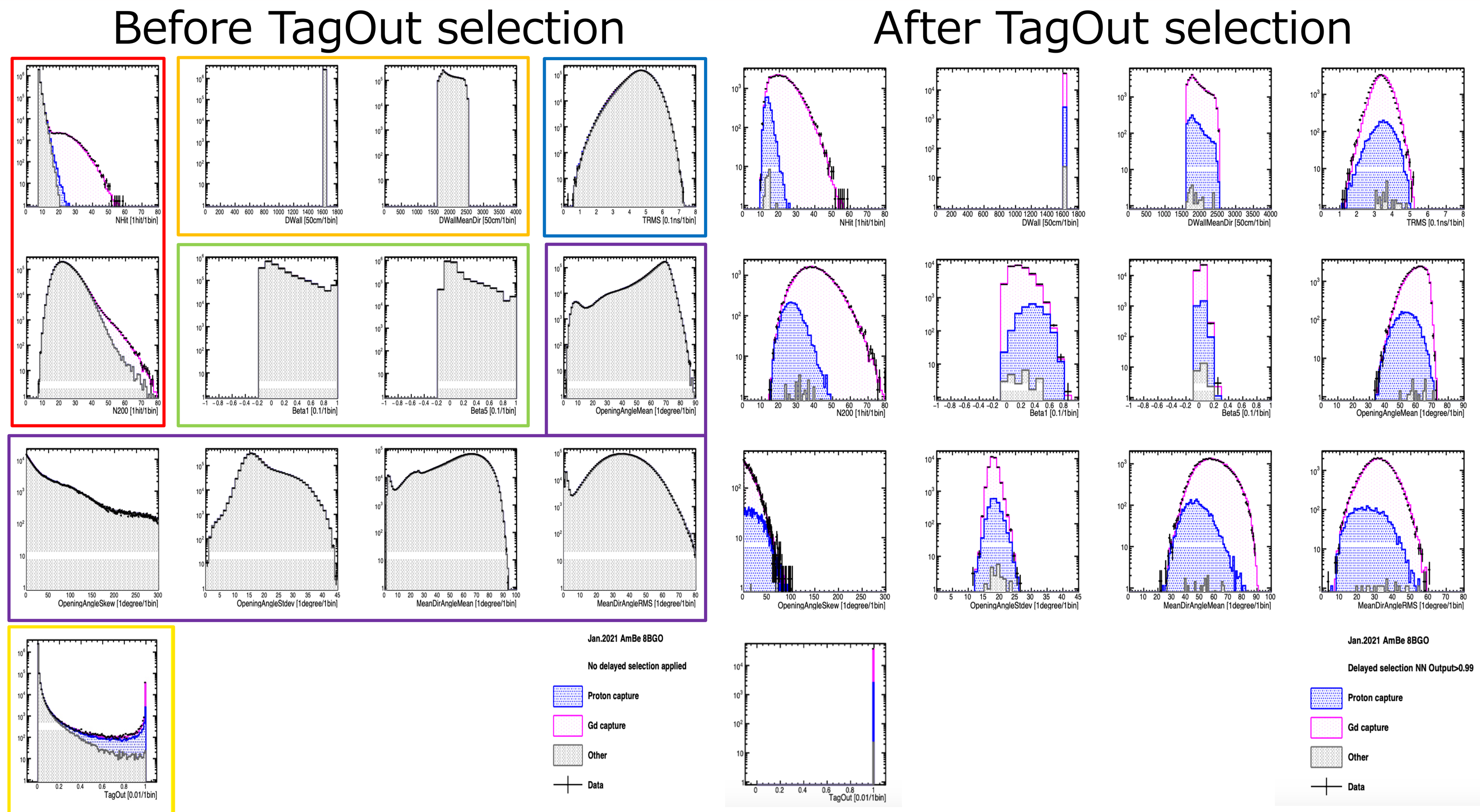
(2)Calculate 12 input variables

- PMT hits
- PMT hit timing
- Mean direction from SK wall
- Harmonic Beta parameters
- Hit pattern

(3)Input the variables into NN and get TagOut value

TagOut: Identification value (0 to 1)

→ **Set the threshold of TagOut**, so that neutron capture events are selected, and BG events are rejected efficiently.



4. AmBe MC simulation

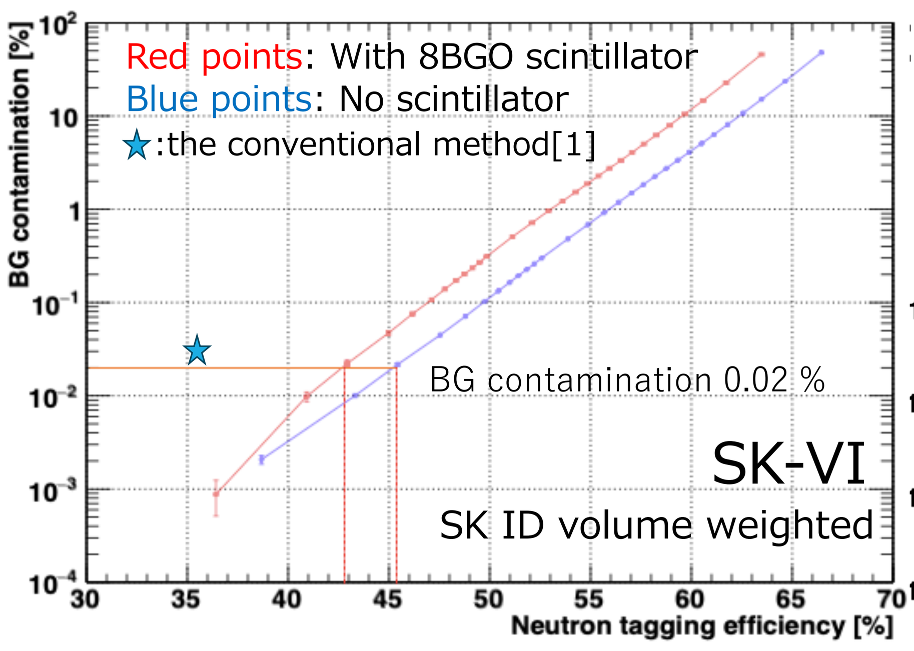
- **Used MC program:** SKG4 (Geant4 for SK system)
- **Injected particles:** ①γ(4.4MeV)+neutron(2~6MeV) or only neutron(②6~10MeV or ③0~3MeV)
- **The number of BGO:** 8BGO(Data and MC) and No scintillator(only MC)
- **BG sample data from SK are appended to the MC.**

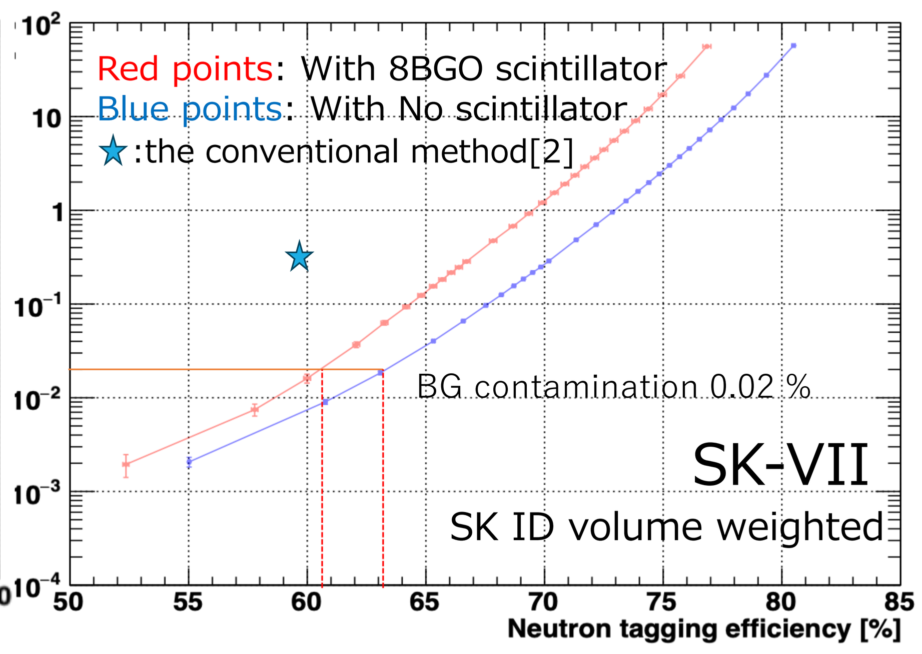
5.Optimization of TagOut threshold with MC

- **Neutron tagging efficiency and BG contamination were calculated by counting tagged as neutron capture events**

$$\text{Neutron tagging efficiency[\%]} = \frac{\text{Total number of tagged Gd and proton events}}{\text{Total number of prompt events}}$$

$$\text{BG contamination[\%]} = \frac{\text{Total number of tagged BG events}}{\text{Total number of prompt events}}$$





6. The results of the tagging efficiency

SK-VI	Neutron tagging efficiency	BG contamination
Conventional methods[1]	35.6 ± 2.5(sys+stat) %	$(2.8\pm0.1)\times10^{-2}$ %
NN analysis	**45.4 ± 3.8(sys+stat) %** Up!	**$(2.0\pm0.3)\times10^{-2}$ %**

SK-VII	Neutron tagging efficiency	BG contamination
Conventional methods[2]	59.7 ± 1.2(sys+stat) %	$(3.3\pm0.6)\times10^{-1}$ %
NN analysis	**63.1 ± 1.1(sys+stat) %** Up!	**$(2.0\pm0.3)\times10^{-2}$ %**

Obtained higher capture efficiency while maintaining low BG contamination in both phase!

※ Breakdown of systematic errors of NN

Source of uncertainty	MC related [%]	Time variation [%]	Position dependence [%]	Data-MC [%]	Total [%]
SK-VI	0.24	0.74	0.73	3.66	**3.81**
SK-VII	0.35	0.36	0.35	0.88(1BGO) 2.19(8BGO)	**1.07**(1BGO) 2.28(8BGO)

7. Prospects

- Systematic error from prompt and delayed events selection will be investigated.
- SK-VII tagging efficiency will be finalized with tuned MC(SKG4).
- NN analysis will be introduced into DSNB analysis

8. Reference

[1] M.Harada, "Search for astrophysical electron anti-neutrinos in Super-Kamiokande with 0.01wt% gadolinium loaded water", arXiv:2305.05135v1

[2] F. Nakanishi, "Evaluation of neutron tagging efficiency on 0.03% Gd mass concentration in SK-Gd experiment", 2023, PoS ICRC2023, 1172.