Study of neutron tagging for Hyper-Kamiokande

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Hyper-Kamiokande

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Introduction

Hyper-Kamiokande(HK)

HK is a next-generation Water-Cherenkov detector which starts construction in 2020.

Photo coverage(p.c.) in base line design is 40%(Table 1).

Photon detection efficiency of HK PMT is twice that of Super-K PMT.

→**Neutron tagging efficiency will be significantly increased.**

	Super-K	Hyper-K
Height	41.4 m	~60 m
Diameter	39.3 m	~74 m
Eff.	22.5 kton	~190 kton
PMT	11146 (p.c. 40%)	~40000 (p.c. 40%)

Table 1 : Detector size comparison with Super-K

Diffuse supernova neutrino background

Diffuse supernova background(DSNB) which is the key to understand the history of universe, is one of the main purpose of HK.
In HK, the number of DSNB events will be dramatically increased due to the large fiducial volume(Fig. 1).

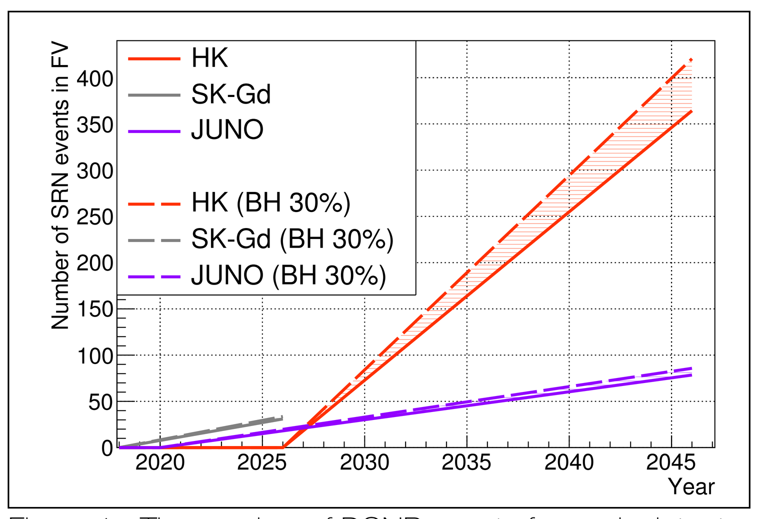

Figure 1 : The number of DSNB events for each detector.

Thermal neutron capture(n-Capture)

In Hyper-K, neutrons are mainly captured by protons and a 2.2 MeV γ-ray is emitted.

"Delayed coincidence detection" using prompt charged signal and delayed neutron signal will be possible in HK. →**Neutron tagging**

Neutron tagging

Identification of neutron events is important for, e.g. detecting neutrino inverse beta decay interaction (Fig.2).

This is the main interaction mode of Diffuse supernova neutrino background(DSNB) in HK.

In Super-K, neutron tagging efficiency is about 20%.
In HK, it will be possible to identify the neutron event with higher efficiency.

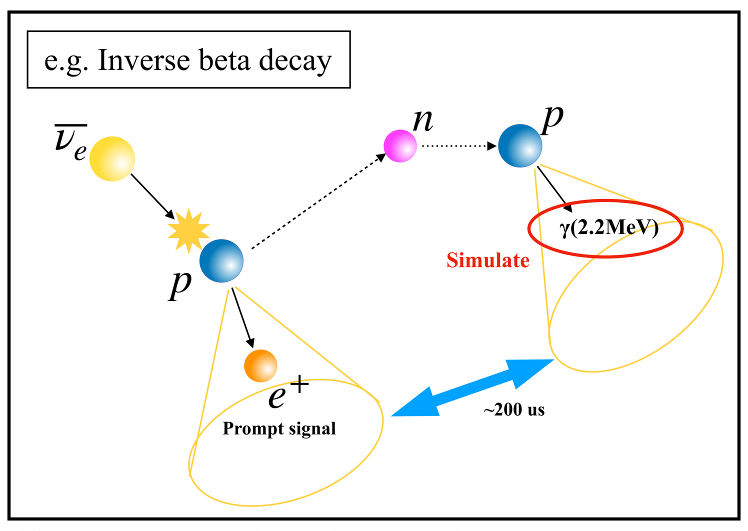

Figure 2 : Inverse beta decay and simulation

Purpose

Construct an algorithm to reconstruct 2.2 MeV γ-ray event and evaluate the neutron tagging efficiency in HK using simulation.

Analysis & Evaluation

Simulation

Geant4[1] based MC simulation was used(Table. 2).

Only PMT dark noise is considered for the background.

Particle	γ-ray 2.2 MeV
# of event	100000 events
Position	Random in the tank
Dark rate	3.0,4.2, 8.4 (kHz)

Table 2 : Condition of simulation

Event candidate search

Maximum cluster of hits within 10 ns window(N10) in (T-TOF) distribution using prompt signal is selected as the 2.2 MeV γ-ray signal candidate.

N10 threshold for the number of hits is set for each dark noise so as to select 100 noise events in 1 ms.

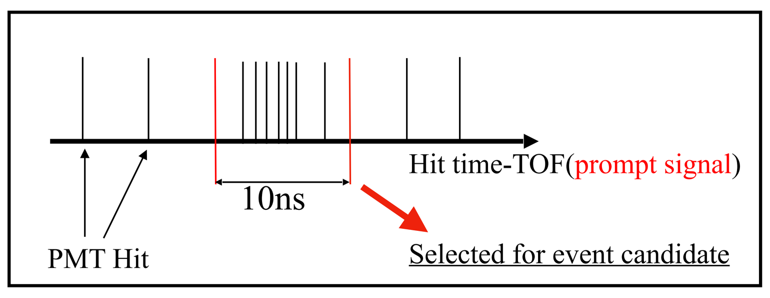

Figure 3: Event search method

Evaluation scheme

Candidate event(2.2 MeV γ & dark) → Event reconstruction → Reconstructed Event

Candidate event(Dark only) → Event reconstruction → Reconstructed(Background) Event

→ Neural network → Tagging Efficiency

Position reconstruction

Prompt signal information is used for the candidate search.
→Reconstruction of n-Capture position is needed.
→Position is reconstructed within 500 cm of prompt signal because neutrons are typically captured within 500 cm.
→Hit time within ~1 ms is used.

Result of reconstruction

Resolution <300cm is achieved(~8% in Volume).

Tail part of (Fig.4) is seems to be mis-identified event.These event is should be removed by analysis.→Multi variate analysis(Neural network[2])

Dark rate	# of event	Resolution (1σ)	Tail part event
0.0 kHz	74630	**252 cm**	**3529**
3.0 kHz	83895	**277 cm**	**7136**
4.2 kHz	81669	**279 cm**	**7268**
8.4 kHz	74595	**283 cm**	**7689**

Table 3 : Number of candidate event and resolution.

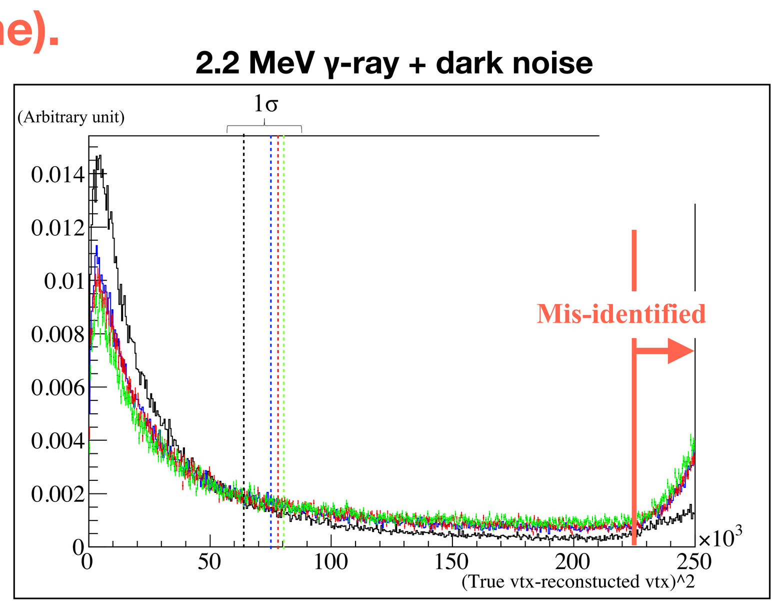

Figure 4 : Resolution of reconstruction and tail-part

Neural network

Candidate event is identified as either neutron or background. Analysis was based on 5 variables. (PMT acceptance, Opening angle, N10, n-capture time, Goodness of position reconstruction)

Cut condition : Mis-identify ratio in 1 ms is less than 10%(Fig. 5).

Analysis result

Detection efficiency in Neural network is estimated.
Removed event is more than expected in (Table. 3).
Some signal events were removed.
→Other good variable may exist.

Dark rate	TMVA eff.	Rejected event
3.0kHz	87%	10868
4.2kHz	83%	13785
8.4kHz	73%	20038

Table 4 : Signal identification & cut(e.g. Dark rate 8.4 kHz)

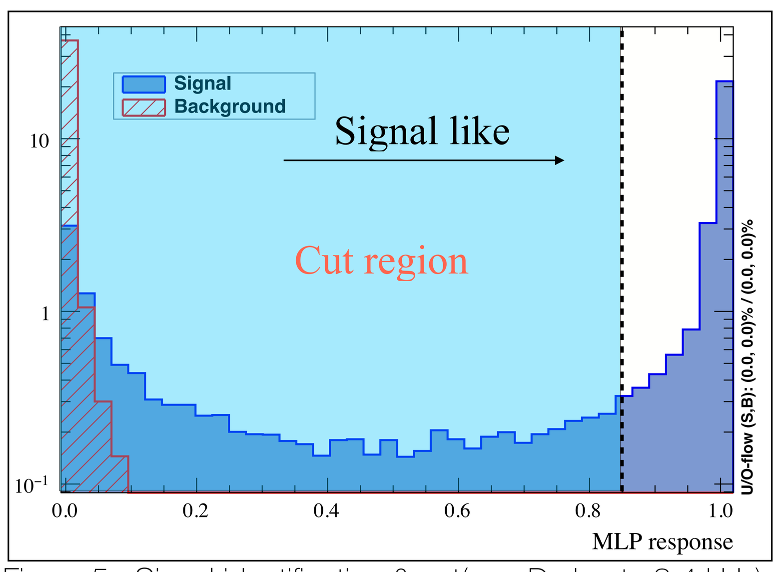

Figure 5 : Signal identification & cut(e.g. Dark rate 8.4 kHz)

[1]S. Agostinelli et al. Nucl.Instrum.Meth. A506 (2003) 250-303
[2]A. Hoecker et al., "TMVA 4 Toolkit for Multivariate Data Analysis with ROOT Users Guide" 2017

Results

Tagging efficiency(T.E.)

T.E. for each dark rate was evaluated(Fig. 6).
T.E. is defined as

Candidate×TMVA eff./100000

Confirmed that T.E. has linear dependence on the dark rate.
HK has twice the T.E. as Super-K even with dark rate 8.4kHz.

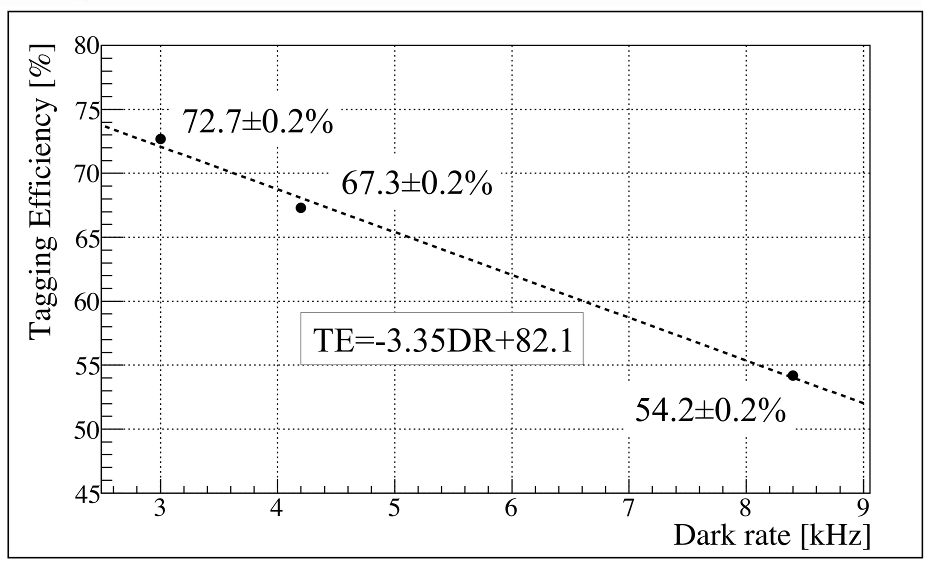

Figure 6: T.E. for each dark rate and dependence on dark rate.

Photo-coverage dependence

T.E. for 20% and 40% of p.c. was evaluated (Fig. 7).

The impact of higher p.c. is greater as the dark rate increases.
→**The p.c. is important for T.E. because HKPMT is expected to have high quantum efficiency (QE) and high dark rate.**

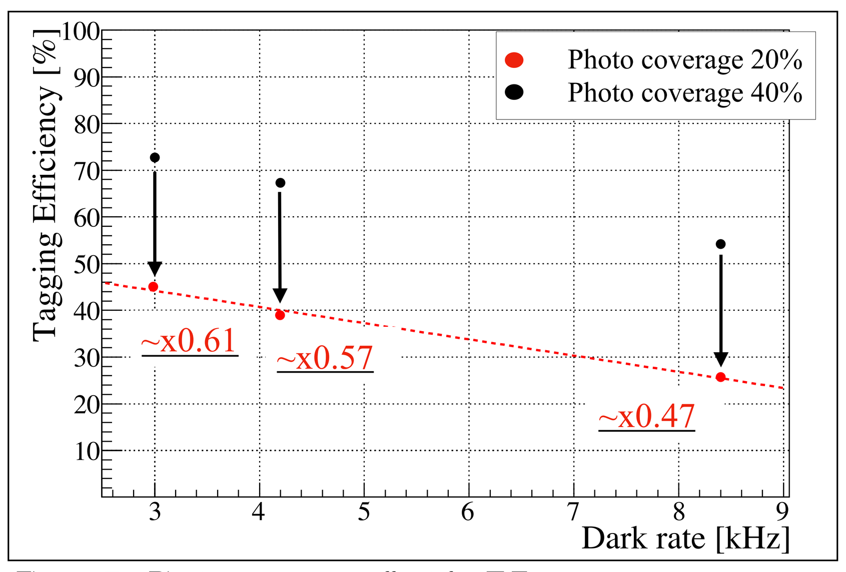

Figure 7 : Photo-coverage effect for T.E.

—Comparison with other settings—

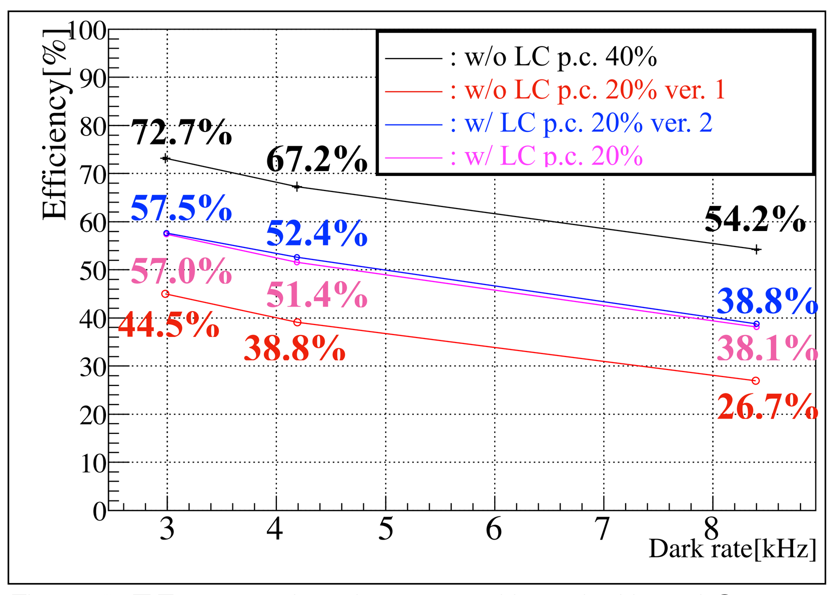

Figure 8: T.E. comparison between with and without LC.

Light cone(LC) simulation

By using LC, it is expected that light collection efficiency is dramatically improved(~40%).

T.E. with LC at 20% p.c. was evaluated by same algorithm and dark rate(Fig.8).

LC effect was estimated more than ×1.3 T.E. in neutron tagging

DSNB sensitivity

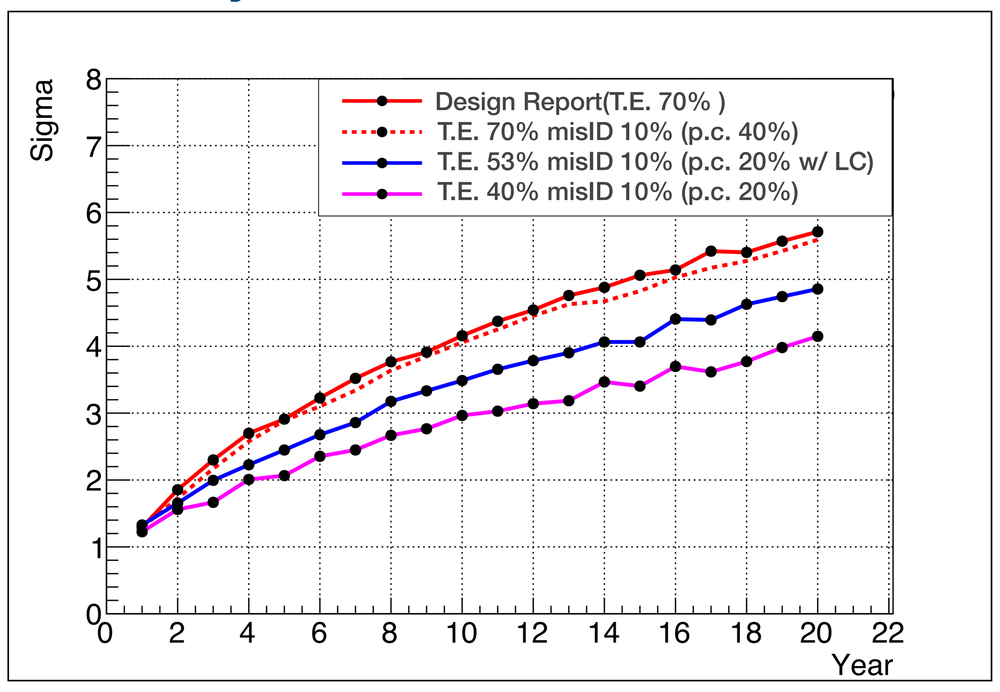

Figure 9 : Sensitivity of DSNB for each setting

(Fig. 9) shows the sensitivity of DSNB in HK for each setting(made by T.Yano).

The importance of p.c. on DSNB search with neutron tagging can be clearly seen from Fig. 9.

Conclusion & Summary

In HK, neutron tagging is expected to be effective for DSNB, proton decay or other searches.

- ☑Reconstruction method using prompt signal information was constructed and the resolution was evaluated.
- ☑T.E in 1 ms was evaluated by using reconstructed information for each dark rate. Since HK PMTs are being developed aiming for T.E. 70%, then this result helps define the p.c. and dark rate required.
- ☑The effect of p.c. was evaluated. The importance of high p.c. was confirmed. **For DSNB search, it was confirmed that p.c. is crucial.**
- ☑The effect of LC was evaluated. Attaching LC is ×1.3 T.E. more effective for neutron tagging.

This result is used in the current calculation of HK's physics sensitivity related to neutron tagging.