Improvement of pulse shape discrimination analysis for background reduction in CANDLES

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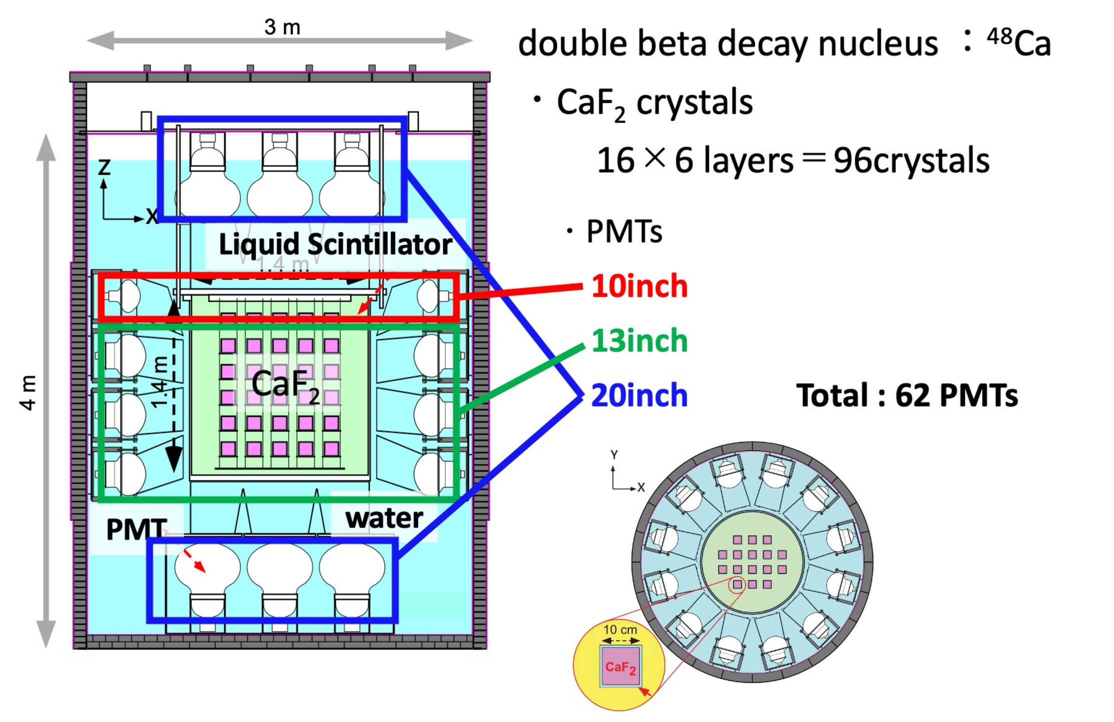
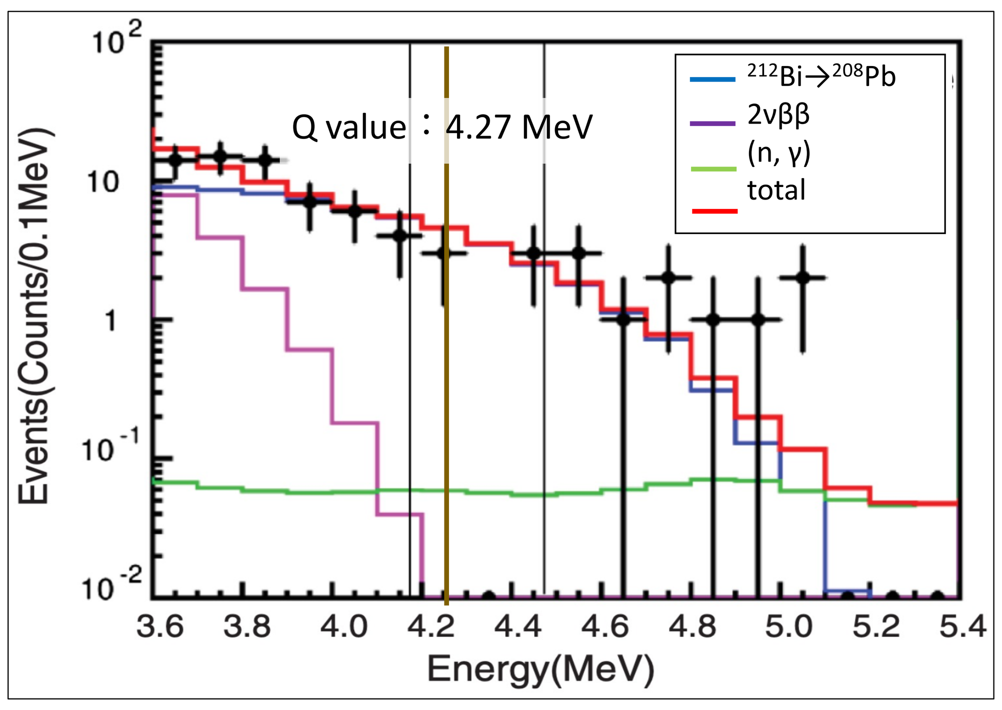
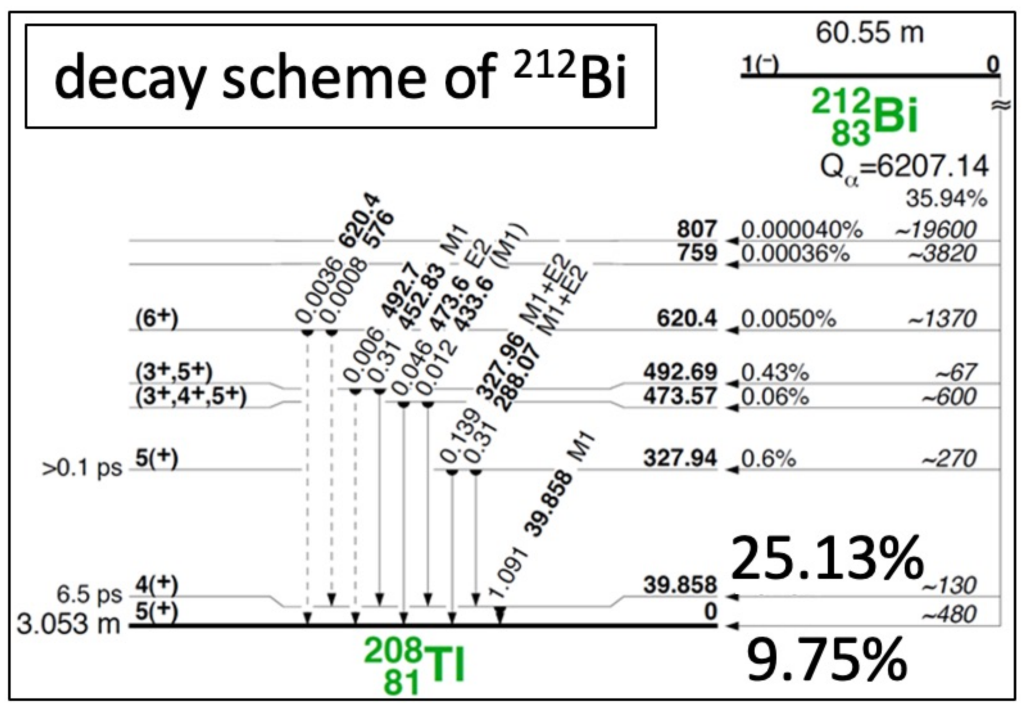
Introduction

CANDLES is an experiment using CaF_2 crystals to search for the neutrino-less double beta ($0\nu\beta\beta$) decay events of ^{48}Ca with a Q = 4.27 MeV. CANDLES uses waveforms to examine information on alpha ray and beta ray. CANDLES device is shown in the figure below.





source : Phys. Lett. D 103, 092008 (2021)



source : Table of Isotope

◯Background events in 130.4 days with 93 crystals

◯The dominant background is beta decay of ^{208}Tl in $^{212}Bi \to ^{208}Pb$ sequential decay (blue)

◯We want to reduce the BGs by identifying the prompt alpha decay of ^{212}Bi based on MC simulations

◯Because some of ^{212}Bi's decays contain γ in addition to α, we need reproduce the impure events

◯Because we identify radiations using the different waveform of α and β (or γ), we need reproduce the features of waveforms of the sum of α and γ radiations

Pulse Shape Discrimination

We use Pulse Shape Discrimination (PSD) technique to identify radiations. The parameter that indicates α-ray is named PSD_α, and the parameter that indicates β-ray is named PSD_β. We prepare reference waveforms.

pure α events : delayed α events of $^{219}Rn \to ^{215}Po \to ^{211}Pb$

pure β events : gamma rays of ^{208}Tl due to external

◯how to calculate PSD_α

First, the tail of the waveform of the real data is fitted with the tail of the α reference waveform.

Second, the normalization factor obtained by fitting is applied to the waveform of the real data, and PSD_α is calculated near the peak using the following equation :

$$PSD_\alpha = \frac{1}{dof}\sum_i \left(\frac{P.H._i - \overline{P.H.}_{\alpha_i}}{\sigma_i}\right)^2$$

dof : the degree of freedom, $P.H._i$: the pulse height of the real data at time i, $\overline{P.H.}_{\alpha_i}$: the pulse height of the alpha reference waveform at time i, σ_i : the error at time i

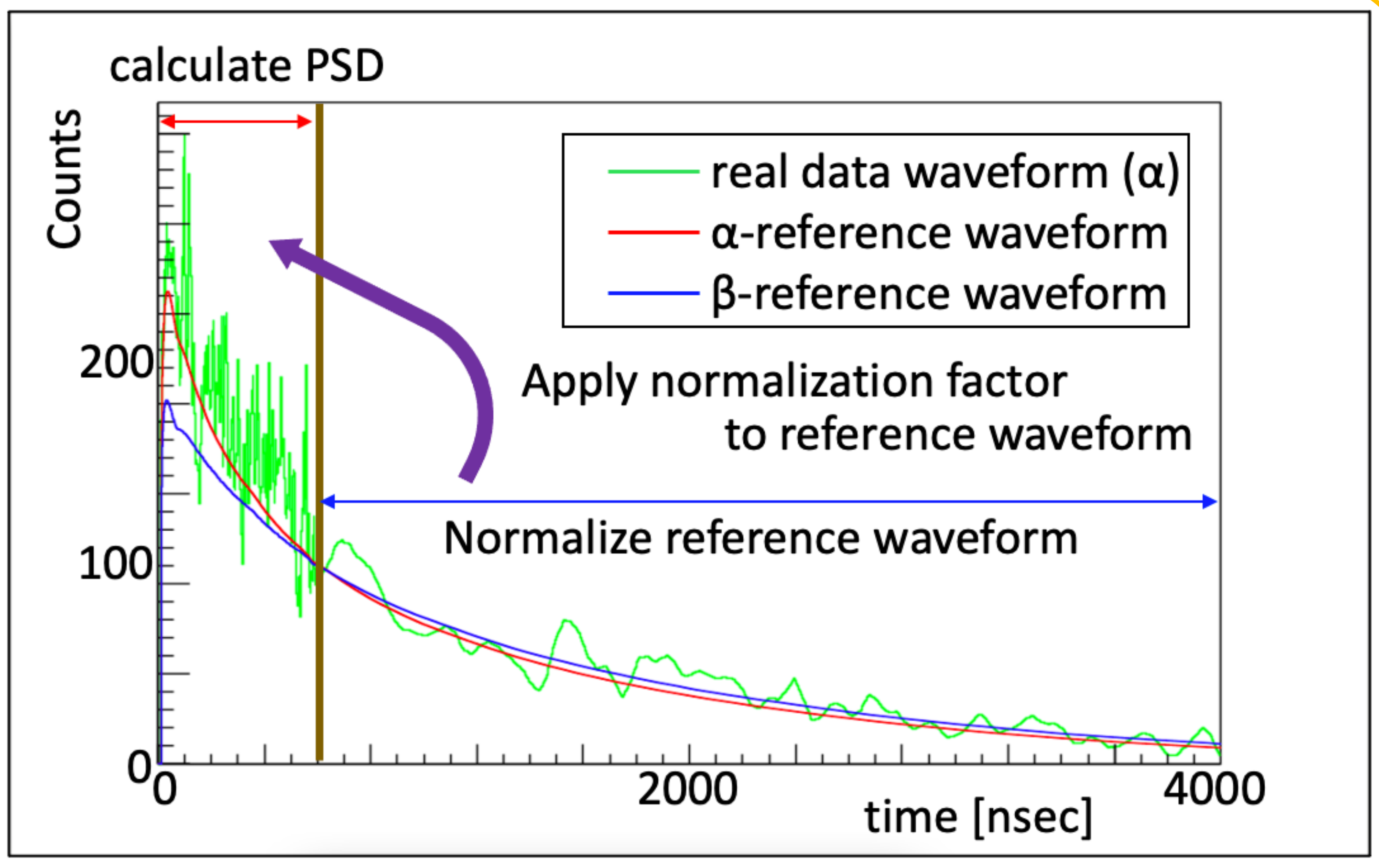
Since the pulse height follows a Poisson distribution, σ_i is proportional to the square root of the pulse height, and expressed by the following equation :

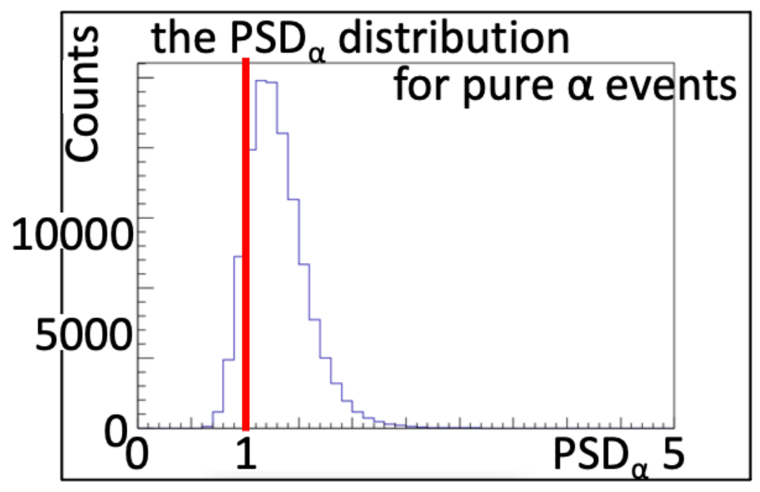
$$\sigma_i = \sum_j \sigma_{j_i}, \qquad \sigma_{j_i} = \frac{A_j}{\sqrt{\sigma_{pe_j}}} \cdot \sqrt{P.H._{ij}}$$

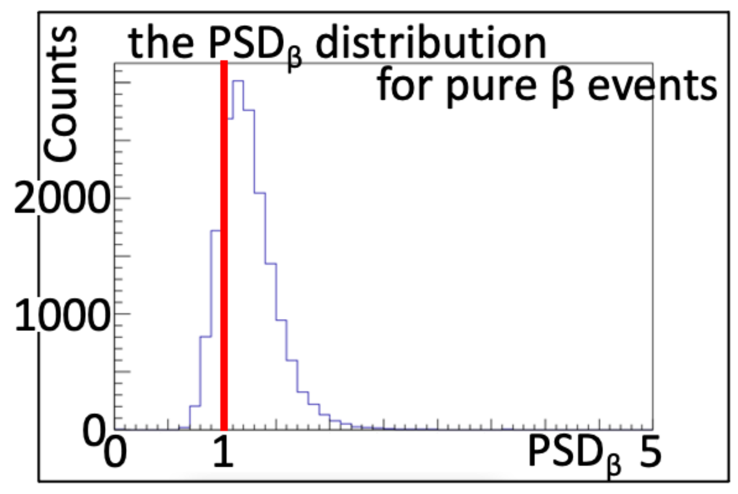
j : PMT types, 10inch, 13inch and 20inch, A_j: constant values

σ_{pe_j} : the one photoelectron width (fixed values for each PMT type)

In the case of PSD_β, the same is done using the β reference waveform for fitting and calculation.







	PSD_α for pure α events	PSD_β for pure β events
mean	1.339	1.265
Std Dev	0.3018	0.2830

PSD is the form of the χ-square of the calculation range. Thus, the mean value of the PSD_α distribution for pure α events and the PSD_β distribution for pure β events should be 1. However, the mean value of the actual distribution is greater than 1 in both cases.

Improvement of PSD

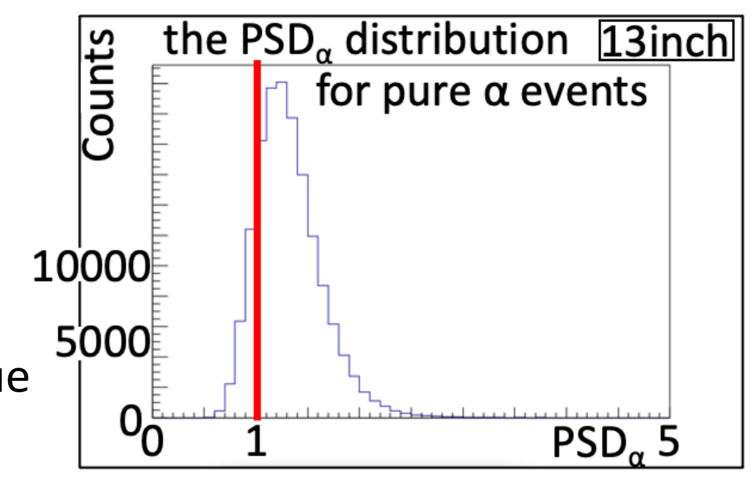
There is one free parameter in the estimation of σ_i .

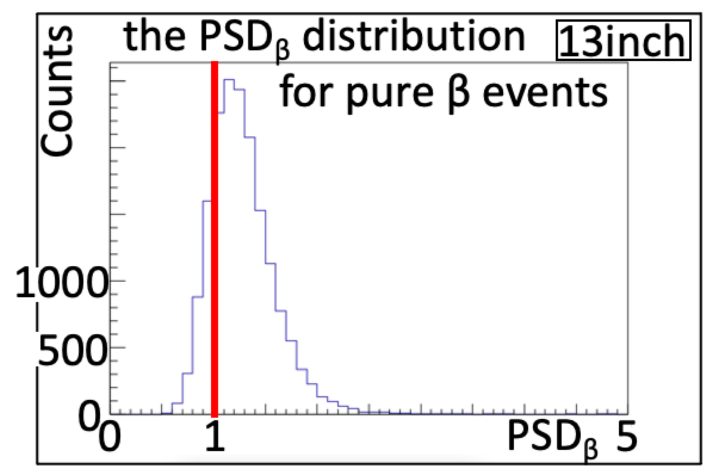
We try to tune the parameter to realize PSD ~ 1 for pure radiation events.

Because there are three σ_{pe_j} for three PMT types (10, 13, 20 inch), we created three different PSD for those three types of PMTs for both alpha and beta and obtain mean value of PSD.

We adjust σ_{pe_j} to realize mean value of each PSD to 1.

Since there are PSD_α and PSD_β for each PMT type, we take mean of σ_{pe_j} obtained from them.

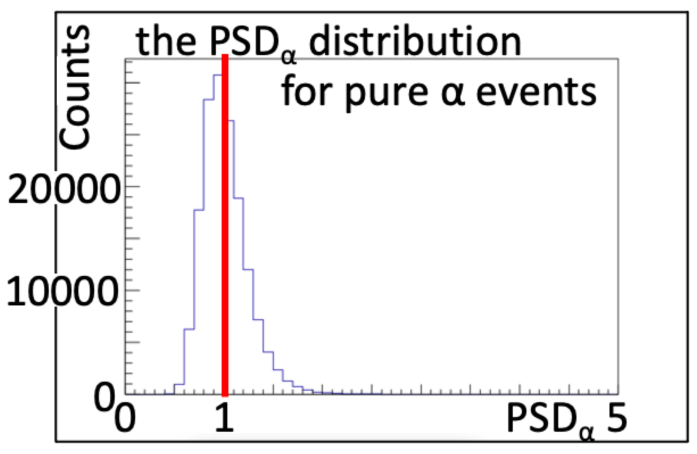


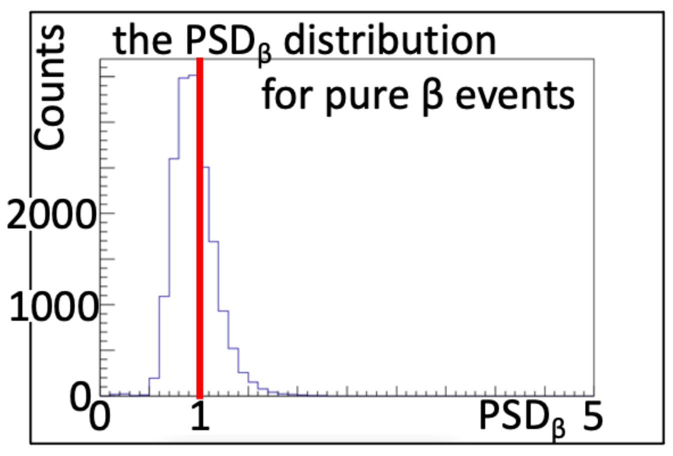


13inch	PSD_α for pure α events	PSD_β for pure β events	weighted mean
mean	1.321	1.279	1.317
Std Dev	0.3194	0.3134	

Result

The PSD_α distribution for α events and the PSD_β distribution for β events after adjusting the value of sigma_1pe are shown in the figure below. In this case, the mean value of PSDα was 1.014 and the mean value of PSDβ was 0.9576, much closer to 1.





	PSD_α for pure α events	PSD_β for pure β events
mean	1.014	0.9576
Std Dev	0.2311	0.2143

Conclusion

CANDLES is an experiment to search for $0\nu\beta\beta$ decay events in ^{48}Ca.

There was a problem that could not be reproduced by MC.

We thought the cause was that the mean value of PSD was not 1.

After adjusting the value of σ_{pe_j} for each PMT type, the average value of PSD approached 1.