

Background Measurement for Neutrino less Double Beta Decay with CANDLES

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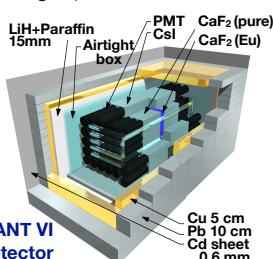
Introduction CANDLES is a neutrino less double beta decay ($0\nu\beta\beta$) experiment using ^{48}Ca in CaF_2 crystals. A distinctive characteristic of ^{48}Ca is the highest Q value (4.3 MeV) among $0\nu\beta\beta$ nuclei, and it enables us to measure signals in low background contribution. As a background reduction, pulse shape discrimination is a key in CANDLES. Here we discuss the background studies for $0\nu\beta\beta$ search, starting from ELEGANT VI experiment which is a preceding experiment of CANDLES.

0. ELEGANT VI - A Preceding Experiment of CANDLES

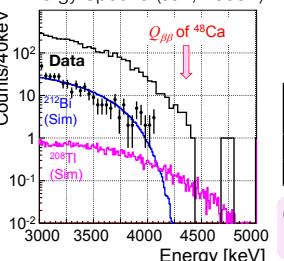
Has given the best sensitivity of $0\nu\beta\beta$ decays among experiments with ^{48}Ca

Comparison of Detector & Shield Structure

Experiment	ELEGANT VI	CANDLES
Target	$\text{CaF}_2(\text{Eu})$ 6.66 kg	$\text{CaF}_2(\text{pure})$ 305 kg
Active shield	$\text{CaF}_2(\text{pure})$, CsI(Tl)	LS
Passive Shield	$\text{Cu}, \text{Pb}, \text{Li+Paraffin}$, Cd sheet	Water



Energy Spectra (Jan, 2003 -)



Run Summary (Measurements for 4 years)

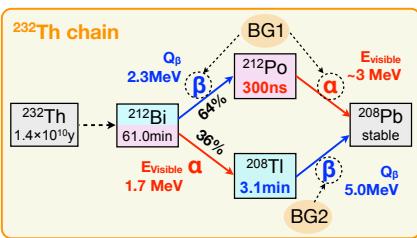
Date	Observed Events	Estimated BG $(^{212}\text{Bi}, ^{214}\text{Bi}, ^{208}\text{Tl})$	Exposure kg · day
Jun 1998 -	0	1.30	1553
Jan 2003 -	0	0.27	3394

$0\nu\beta\beta$ Half life of ^{48}Ca : $T_{1/2} > 5.8 \times 10^{22}$ year
ref. PRC78, 058501 (2008) $<\langle m\rangle < (3.5-22)$ eV

2. Background Criteria

There are three major backgrounds in $Q_{\beta\beta}$: $^{212}\text{Bi}-^{212}\text{Po}$, ^{208}Tl , & (n,γ) reaction.
 ^{232}Th chain (see category 3)

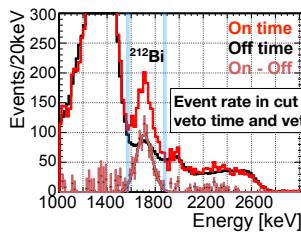
→ Select ^{232}Th -least 26 crystals



BG2. ^{208}Tl ($Q_\beta = 5.0$ MeV)

- Tag ^{212}Bi (α -ray) by PSD, then apply veto-time to the ^{212}Bi -detected crystal for 12 minutes ($4 \times T_{1/2}$)
- Double pulse veto
- α (^{212}Po) pulse veto
- Ignorable BG level

Prompt Spectrum of $^{212}\text{Bi}-^{208}\text{Tl}$ Coincidence



Summary of ^{208}Tl Rejection Efficiency

a detection eff.	85%
DAQ eff.	98%
Veto time	93%
Same crystal veto	77%
Total	60%

^{208}Tl in $Q_{\beta\beta}$: ~ 1 events/26crystals/60days
→ Improved PSD and better energy resolution will help to reduced ^{208}Tl BG.

4. $0\nu\beta\beta$ Analysis

Data set and resolution

- Jun. - Sep., 2013
- Run time = 61.7 days
- Energy resolution
2.6% @ 4.27 MeV
- Window: 4.17 - 4.48 MeV

Event selection

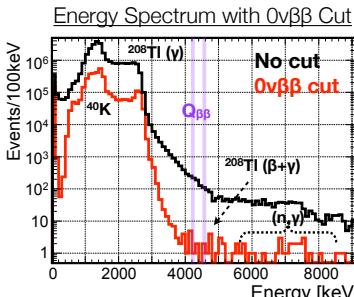
- $\chi^2_\beta < 1.5$ (remove CaF_2+LS signal)
- $-3\sigma < \text{Shape Indicator} < 1\sigma$ (β selection)
- Double pulse cut ($^{212}\text{Bi}-^{212}\text{Po}$ rejection)
- 12 minutes veto after ^{212}Bi (^{208}Tl rejection)
- 26 crystals selection ($^{232}\text{Th} < 10 \mu\text{Bq}/\text{kg}$)

Results

LiveTime	60.3 days
Exposure	4987 kg · days
Cut Efficiency	0.28
Observed Events	6
Estimated BG	4.4
Sensitivity ($T_{1/2}$)	$> 0.8 \times 10^{22}$ year

- Exposure is almost equivalent to ELEGANT VI.
- BG breakout: $^{208}\text{Tl} \sim 1$, $(n,\gamma) = 3.4$

→ Goal of BG reduction: ~ 1 events



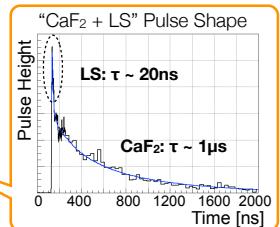
1. Pulse Shape Discrimination

Purpose

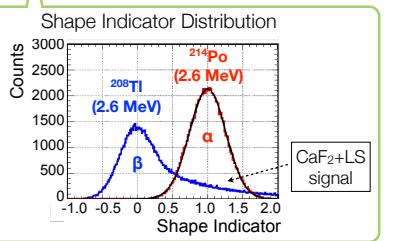
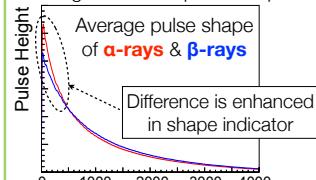
- Select events with CaF_2 scintillation only (−: $0\nu\beta\beta$ signal is β -rays)
- Discriminate α -rays from β -rays for BG study

→ see category 2

- Remove LS only signals by Hardware
- Remove “ $\text{CaF}_2 + \text{LS}$ ” signals for $E_L > 100$ keV using χ^2 analysis
- Discriminate α -rays from β -rays using “Shape Indicator” PRC67, 014310 (2003)

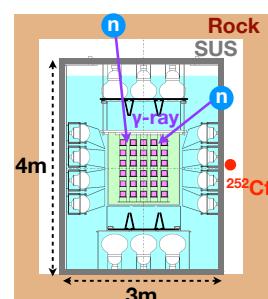


Average Pulse Shape of α & β

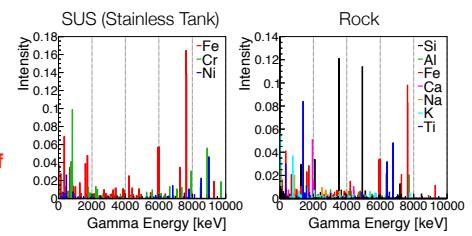


3. (n,γ) Background

We found that gamma rays from neutron captures on materials surrounding detector (Stainless tank, rock) can be dominant background.

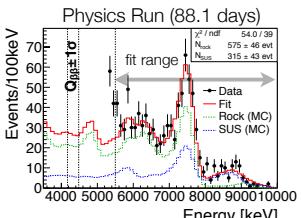


γ -ray Energy from (n,γ) Reaction



ref. Database for Prompt Gamma-ray Neutron Activation Analysis (<https://www.nds.iaea.org/pgaa/>)

Comparison of (n,γ) Spectrum between Data and MC



Strategy of (n,γ) Study

• Neutron source run (^{252}Cf)

- for better understanding of (n,γ) reaction
- 1 hour of source run = 1 year of physics run

• Detector simulation of (n,γ)

- Geant4.9.6.p02
- Generate γ -rays uniformly in SUS or rock according to γ -ray spectrum of (n,γ) reaction



✓ Data spectrum is well reproduced by MC

- Various cut efficiency for $0\nu\beta\beta$ analysis can be checked with source run.
- (n,γ) BG in $Q_{\beta\beta}$ is evaluated from MC spectrum.

Results

Rock/SUS = 3.6 ± 0.7 in $Q_{\beta\beta} \pm 1\sigma$

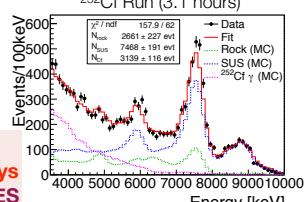
(n,y) BG = 3.4 ± 0.4 events/26crystals/60days

Largest background in CANDLES

Need to shield “ γ -rays from rock” and “neutrons on SUS”

- γ -ray shield: Water or Pb outside of detector
- Neutron shield: B-loaded sheet on the surface of detector

Target BG amount: < 0.5 events



Summary & Conclusions

CANDLES is a $0\nu\beta\beta$ measurement using 305 kg of CaF_2 (^{48}Ca 300g). We clarified background sources as ^{208}Tl and (n,γ) . The former can be reduced by PSD improvement and more accurate ^{212}Bi tagging. For the latter, we plan to place shields for γ -rays and neutrons outside of the detector. By these updates, CANDLES aims 0 consistent background level. Please pay attention to the updated CANDLES!