The CANDLES experiment for the study of Ca-48 double beta decay

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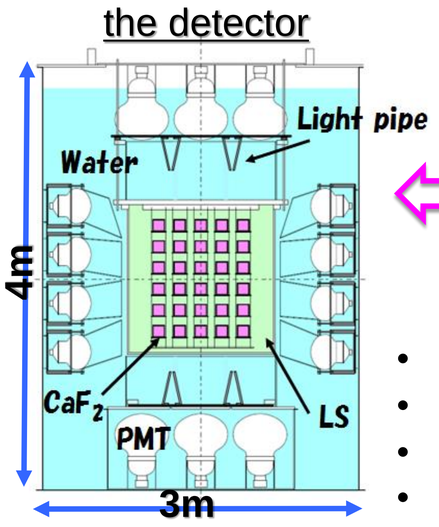
The CANDLES detector

Schematic view of the detector



➢ **CANDLES** aims to perform the world's most sensitive $0\nu\beta\beta$ search by studying ^{48}Ca which has largest Q-value (4.27MeV) among all the $0\nu\beta\beta$ nuclei. Taking this advantage, we aim background (BG) free measurement !!

⇦ **The CANDLES III (U.G.) detector** is currently running 1,000m underground in Kamioka observatory, Japan.

- 96 pure CaF_2 crystals (305kg)
- 62 photo-multipliers (13" & 20" PMTs)
- 780 p.e./MeV after Light pipe installation (×1.8)
- 4π active shield※ by liquid scintillator (LS)

※Time const. = 1μs for CaF_2 / ~20ns for LS

Data taking status from NEUTRINO 2012

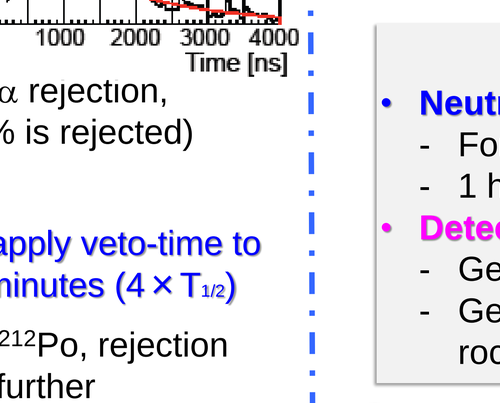
Data taking LiveT = 36days → 2012 Nov. → DAQ update → 2013 Jun. → Data taking LiveT = 61days → 2014 Jan. → Detector update → Now!!

Detector performances

- Energy scale (Escale) is calibrated using ^{88}Y γ-ray source (1.84 MeV).
- For each 96 crystals, **Escale is adjusted with 0.2% accuracy**.
- Escale linearity is checked using external γ-rays (e.g. 2.62 MeV of ^{208}Tl) and neutron capture γ (e.g. 9.0 MeV of ^{58}Ni) calibration.

- Energy resolution and detector stability are checked by several energy γ/α BG events. **Very good stability** has been confirmed (see the table).

Linearity of Escale



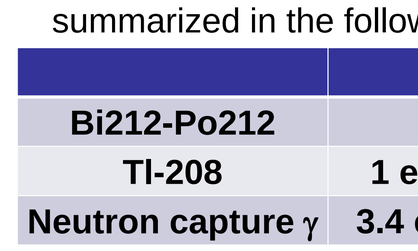
Summary table of the detector performance

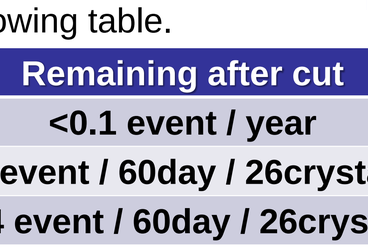
Energy resolution	σ = 2.56% @4.27MeV
Time dep. of Escale	0.3%
Position dep. of Escale	0.5%
Time dep. of event rate	2.4%

Background study

1. Pulse shape discrimination

- Decay time of β / α in CaF2 is different as shown in the figure. In CANDLES, **pulse shape discrimination (PSD)** is used for BG rejection.





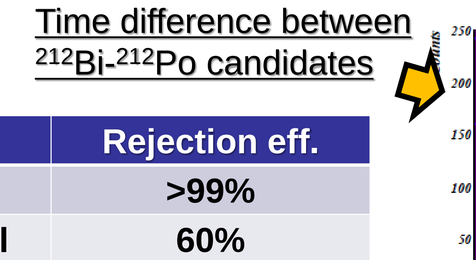
CaF2+LS signal

- Discriminate β / α using "Shape Indicator" PRC67, 014310 (2003).
※ Most of LS events are rejected by hardware and χ^2 pulse shape analysis.

- Here we discuss a BG study by PSD with 36 days 1st phase data. See next section!!

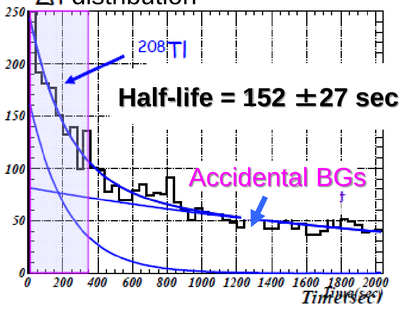
2. Th-chain backgrounds

- **^{232}Th chain** produces two of three main BGs.
→ **Select ^{232}Th-least 26 crystals and apply PSD.**



Two Th-chain BGs in Q-value region.

BG1. ^{212}Bi-^{212}Po



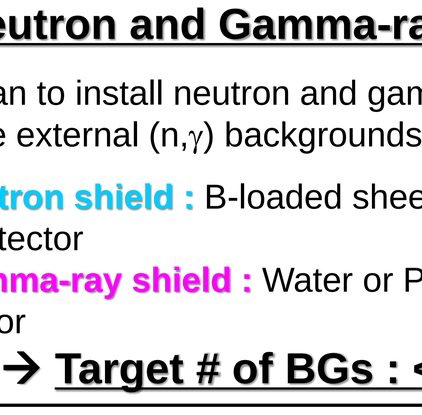
✓ By double pulse rejection and α rejection, **^{212}Bi-^{212}Po is ignorable**. (>99% is rejected)

BG2. ^{208}Tl (Q_β = 5.0 MeV)

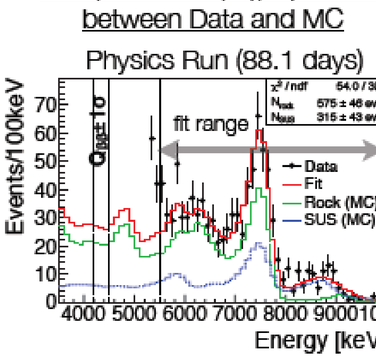
- Tag ^{212}Bi (α-ray) by PSD, then apply veto-time to the ^{212}Bi-detected crystal for 12 minutes ($4 \times T_{1/2}$)

- BUT, due to long decay time of ^{212}Po, rejection efficiency is now only ~60% and further improvement of PSD is necessary.

Time difference between ^{212}Bi-^{212}Po candidates



3. Neutron capture γ BG → (n,γ)



- So far, the origin of high energy BGs was unknown.
- We found that γ-rays from neutron captures on materials surrounding detector (Stainless tank, rock) can be dominant BGs.

Strategy of (n,γ) study

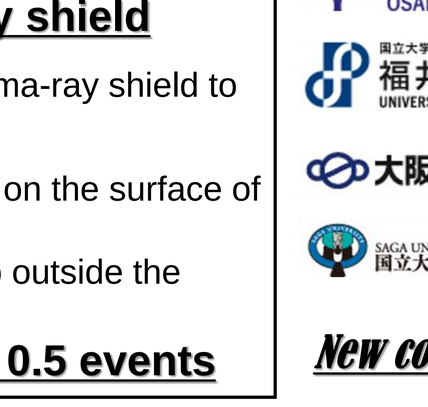
- **Neutron source run (^{252}Cf)**
  - For better understanding of (n,γ) reaction
  - 1 hour of source run = 1 year of normal run
- **Detector simulation of (n,γ)**
  - Geant 4.9.6.p02
  - Generate γ-rays uniformly in stainless or rock according to (n,γ) spectrum.

4. Estimated # of BGs

✓ After all BG rejection, # of BGs are estimated by data analysis and MC simulation, and summarized in the following table.

	Remaining after cut	Rejection eff.
Bi212-Po212	<0.1 event / year	>99%
Tl-208	1 event / 60day / 26crystal	60%
Neutron capture γ	3.4 event / 60day / 26crystal	77%

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



✓ **Data spectrum is well reproduced by MC.**

- Various cut efficiency for 0νββ analysis can be checked with source run.
- **(n,γ) BG in Qββ is evaluated from MC spectrum.**

0νββ sensitivity

Analysis data set

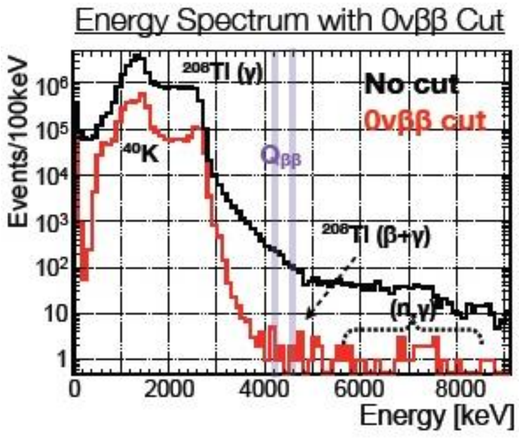
◆ Jun. – Sep., 2013
- Run time = 62 days

◆ Energy window
- 4.17 – 4.48 MeV

Event selection criteria

1. $\chi^2\beta$<1.5 (remove CaF2 + LS event)
2. -3σ < Shape indicator < 1σ (select β)
3. Double pulse cut (reject ^{212}Bi-^{212}Po)
4. 12 minutes veto after ^{212}Bi (reject ^{208}Tl)
5. 26 crystals selection (^{232}Th < 10 μBq/kg)

Energy Spectrum with 0νββ Cut



Preliminary results

Live time	60.3 days
Exposure	4987 kg·days
Cut efficiency	0.28
Observed events	6
Estimated BG	4.4
Sensitivity	> 0.8 × 10^{22} year

- Sensitivity is limited by BGs.
- Improving PSD to reduce BGs.

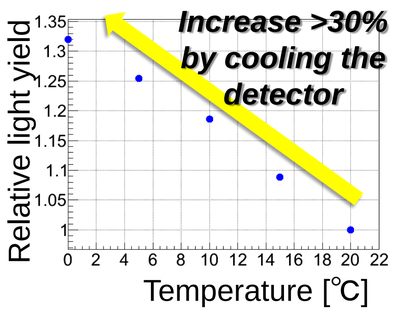
✓ **To achieve better sensitivity, we also develop a ^{48}Ca enrichment technique !!! (0.187% → ??%)**

Future plan

1. Cooling system installation

CaF_2 scintillator is known that its light output increases about 2% by lowering 1℃ temperature.

Cooling system has been installed and will work in this summer!!



2. Neutron and Gamma-ray shield

We plan to install neutron and gamma-ray shield to reduce external (n,γ) backgrounds!!

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

→ **Target # of BGs : < 0.5 events**

Collaborating Institutions

大阪大学 OSAKA UNIVERSITY
RCNP 大阪大学 核物理研究センター
国立大学法人 福井大学 UNIVERSITY OF FUKUI
徳島大学 The University of Tokushima
大阪産業大学 OSAKA SANGYO UNIVERSITY
SAGA UNIVERSITY 国立大学法人 佐賀大学

New collaborator is wanted !!!!