Development of CANDLES detector to search for neutrino-less double beta deca of ^{48}Ca

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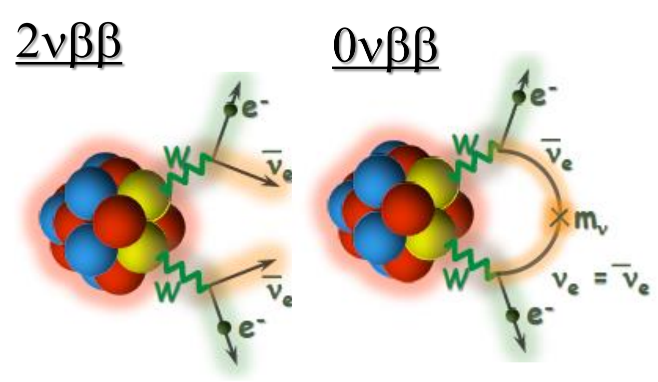
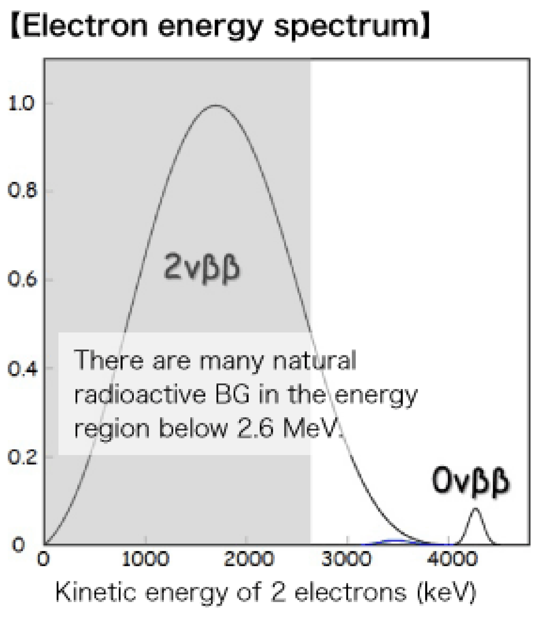
1. Double Beta Decay





Neutrino less double beta decay (0νββ) occurs when neutrino is Majorana particle. This process is beyond the standard model and observation of 0νββ proves the following physical laws;

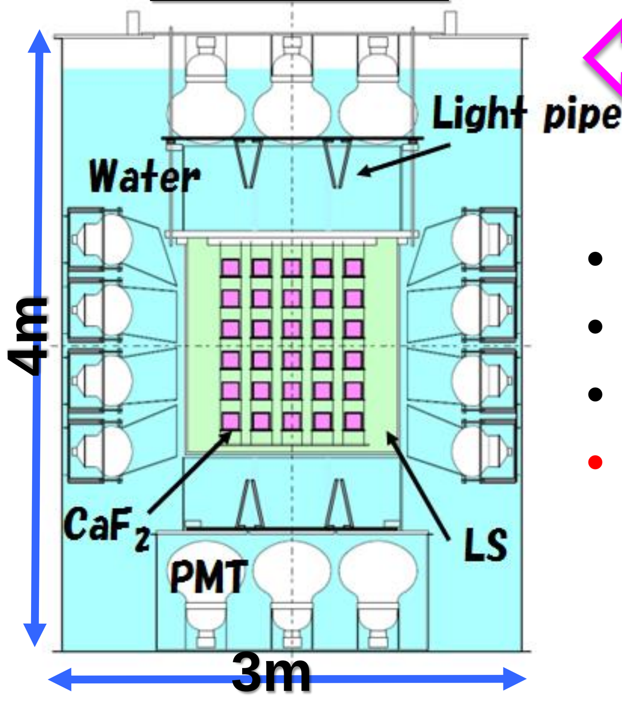
- **Majorana nature of neutrino**
- **Lepton number violation**
- **Neutrino mass and its hierarchy**

➢ Energy spectrum of 0νββ has a peak at Q-value. Because 0νββ is an extremely rare phenomenon, low background (BG) condition is important.

➢ **^{48}Ca has largest Q-value (4.27MeV)** among all the 0νββ nuclei. Taking this advantage, we target **background free measurement !!**

2. CANDLES Detector

Schematic view of the detector



- **CANDLES** is a project to search for neutrino less double beta decay of ^{48}Ca with CaF_2 scintillators.

The CANDLES III (U.G.) detector is currently running at the Kamioka underground observatory, Japan.

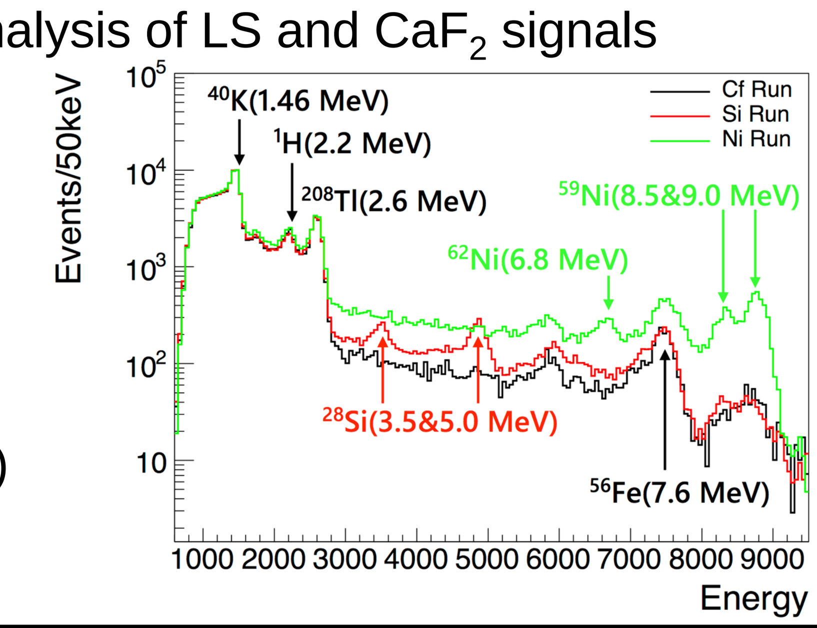
- **96 pure CaF_2 crystals (305kg)**
- **62 photo-multipliers (13” & 20” PMTs)**
- **~ 1000 p.e./MeV after cooling the detector**
- **4π active shielding by liquid scintillator (LS)**
  - Difference of scintillation time constant

  CaF_2 ~ 1000 nsec / LS ~20 nsec

  Pulse shape analysis of LS and CaF_2 signals

Energy Calibration

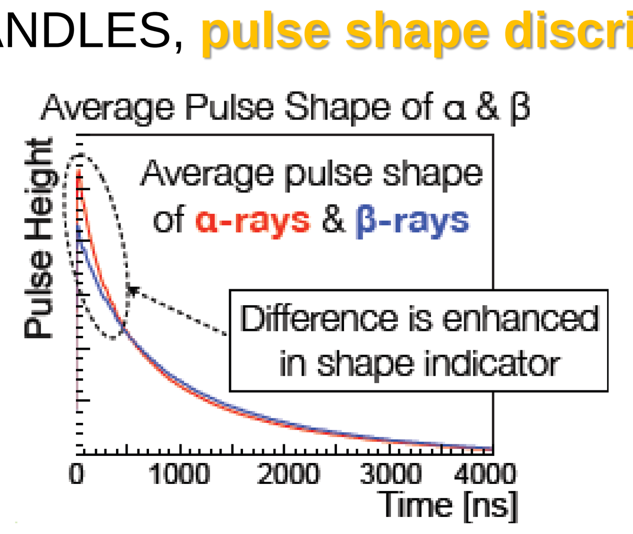
- Energy scale is calibrated using ^{88}Y γ-ray source (1.84 MeV) : Regular calibration.
- The linearity is checked using external γ-rays (e.g. 2.62 MeV of ^{208}Tl) and neutron capture γ (e.g. **9.0 MeV of ^{58}Ni**, **3.5MeV/5.0MeV of ^{28}Si**) calibration.

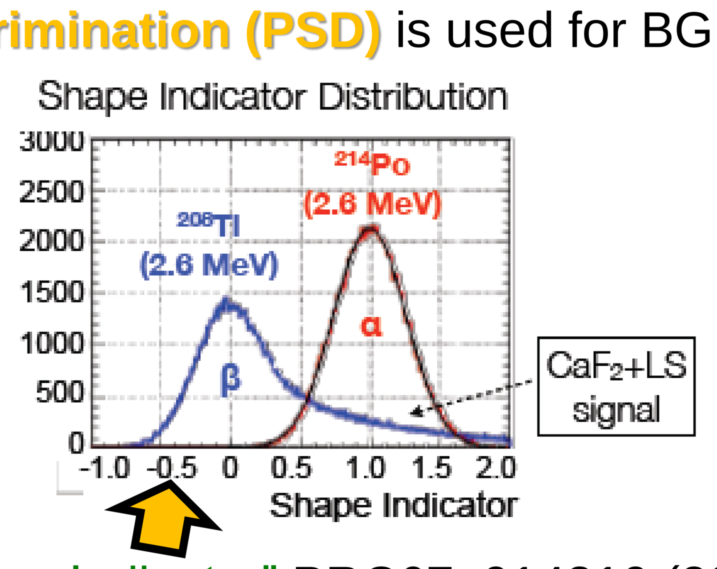


3. Background Study

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.





- Discriminate β / α using “Shape Indicator” PRC67, 014310 (2003).

※ Most of LS events are rejected by hardware and χ^2 pulse shape analysis.

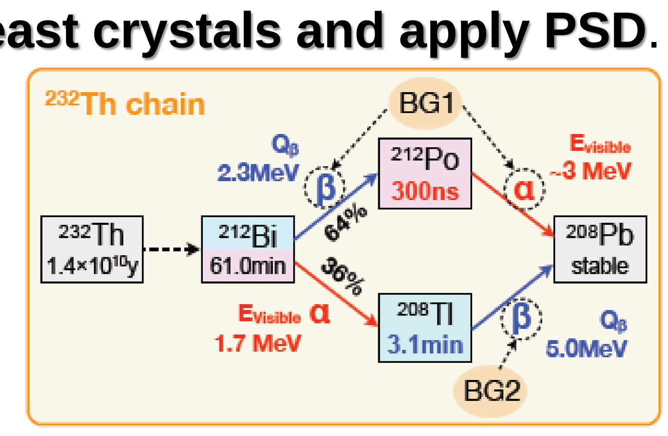
- Here we discuss a BG study by PSD with 36 days 1st phase data.

2. Th-chain backgrounds

- **^{232}Th chain** produces two of three main BGs.

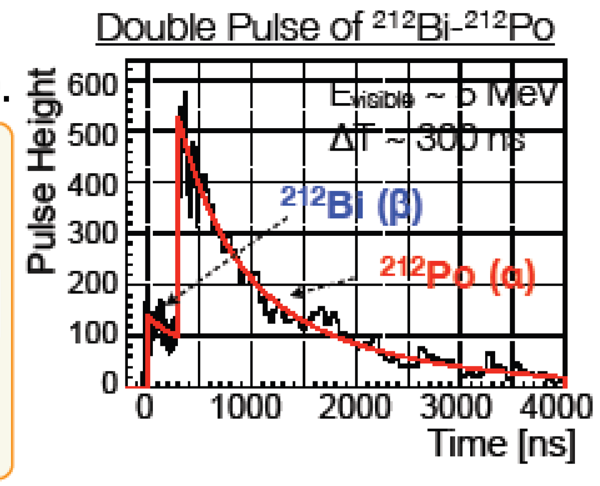
  → **Select ^{232}Th-least crystals and apply PSD.**

Two Th-chain BGs in Q-value region.



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

Double Pulse of ^{212}Bi-^{212}Po



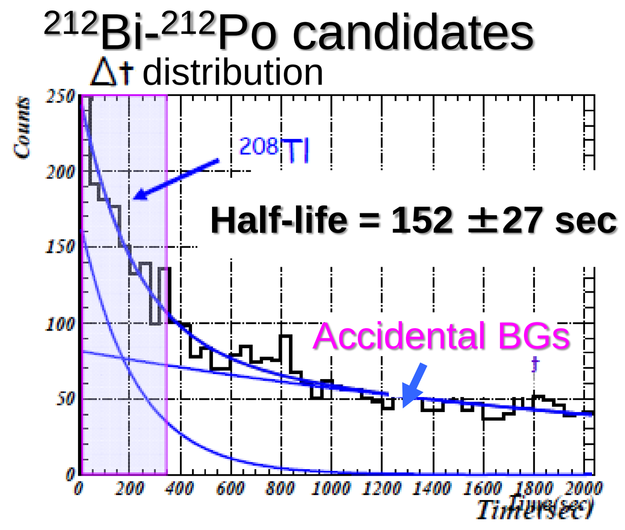
✓ By double pulse rejection and α rejection, **^{212}Bi-^{212}Po is ignorable.** (>99% is rejected)

BG2. ^{208}Tl (Qβ = 5.0 MeV)

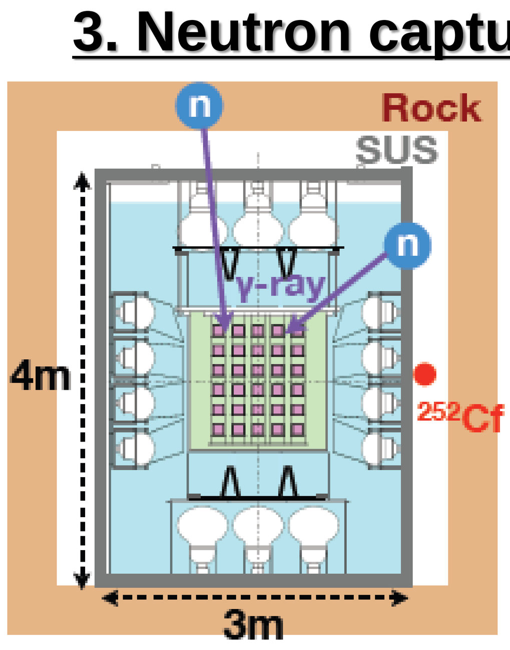
- Tag ^{212}Bi (α-ray) by PSD, then apply veto-time to the ^{212}Bi-detected crystal for 12 minutes (4 × $T_{1/2}$)
- BUT, due to long decay time of ^{212}Po, rejection efficiency is now only ~60% and further improvement of PSD is necessary.

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

Δt distribution



3. Neutron capture γ BG → (n,γ)



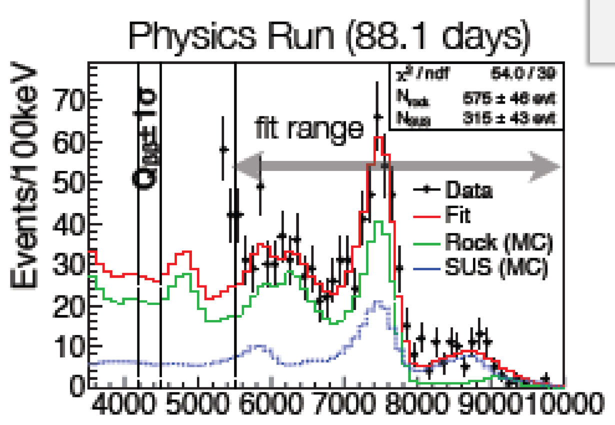
- **γ-rays from neutron captures on materials surrounding detector** (Stainless tank, rock) can be dominant BGs.

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.

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

Physics Run (88.1 days)



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.**

4. Upgrading Detector

1. Cooling system installation

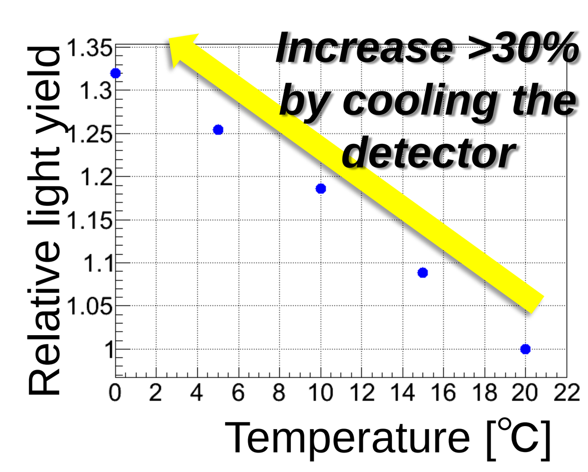
✓ CaF_2 scintillator is known that its light output increases about 2% by lowering 1°C temperature. The cooling system has been installed in the Lab..

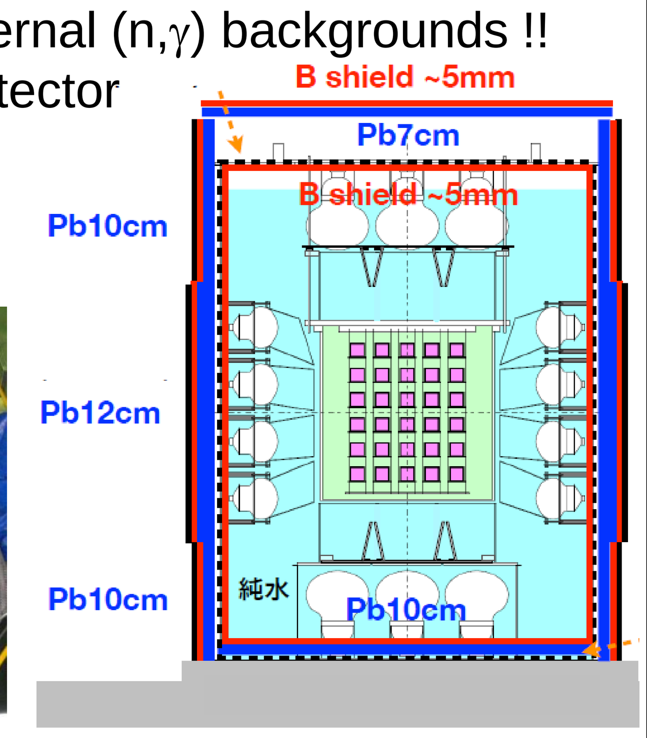
2. Neutron and Gamma-ray shield

We are installing neutron and γ-ray shield to reduce external (n,γ) backgrounds !!

- **Neutron shield :** B-loaded sheet on the surface of detector
- **γ-ray shield :** Pb (7 ~ 12 cm)

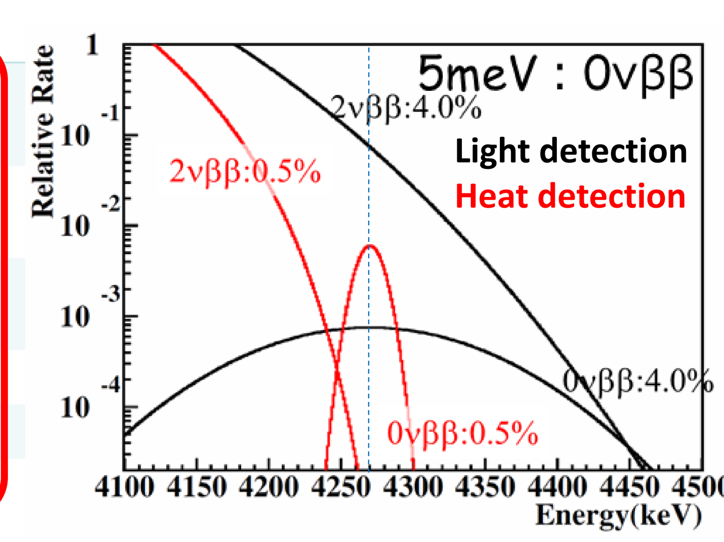
→ **Target # of BGs : < 0.5 events**



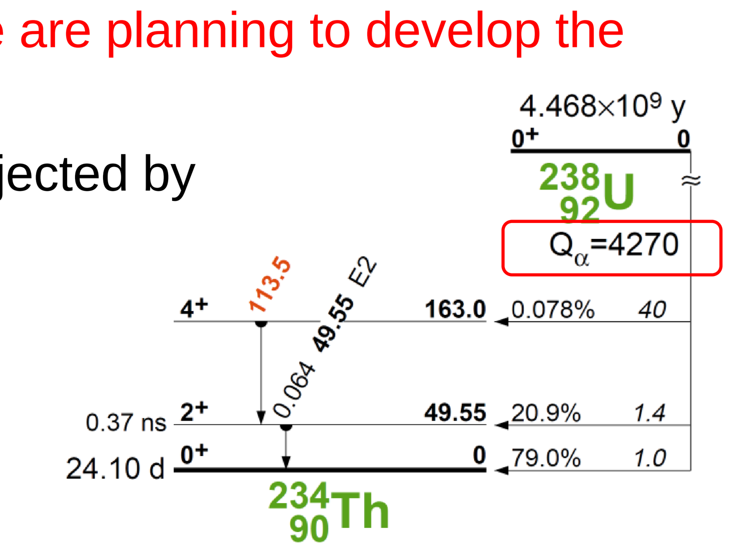


5. Development of Scintillating bolometer

	CANDLES Ⅲ	Next CANDLES	
Crystal Total Mass	3.2kg × 96 crystals 305 kg (350 g)	2 % ^{48}Ca 2 ton (25 kg)	50 % ^{48}Ca 2 ton (610 kg)
Energy Resolution	(4.0 %)	2.8 % (Req.)	0.5 % (Req.)
2νββ ^{212}Bi,^{208}Tl	0.01 0.26	0.1 ~0.1	0.01 ~0.01
Expected BG	0.27/ year	< 0.7/3 year	< 0.2/9 year
$\langle m_\nu \rangle$	0.5 eV	0.08 eV	0.009 eV
	Current system	~2 % enriched ^{48}Ca and cooling system	



- In order to explore the Inverted hierarchy and further normal hierarchy region, we need two improvements:
  - Realizing highly enriched ^{48}Ca, and ton-scale detector
  - Much better energy resolution to avoid 2νββ background events
- In order to achieve good energy resolution, we are planning to develop the scintillating bolometer.
- BG from CaF_2 internal radioactivities can be rejected by
  - Improved energy resolution
  - Crystal segmentation
  - **Quenching effect of scintillation**

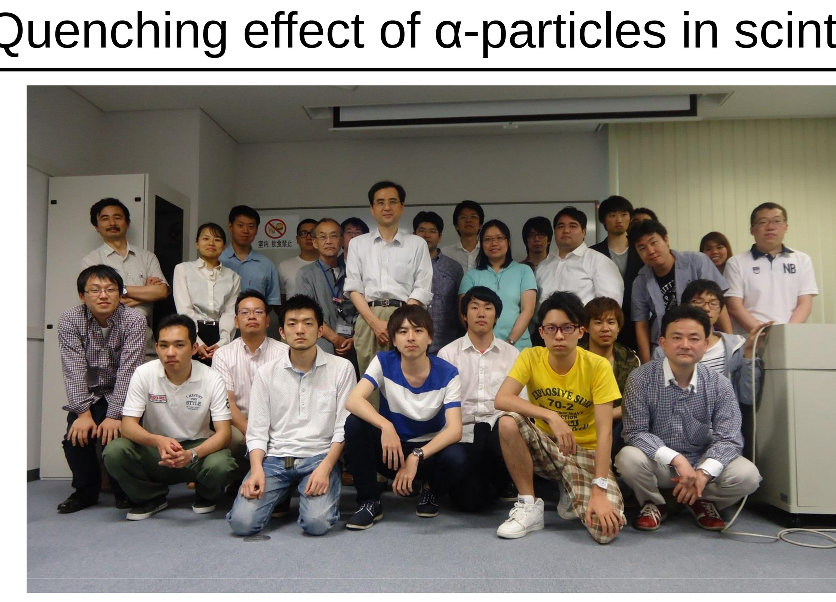


New BG candidate

✓ Q-value of ^{238}U (α-decay) : 4270 keV

✓ Q-value of ^{48}Ca : 4267.98(32) keV

- Quenching effect of α-particles in scintillators can discriminate the ^{238}U α-BG.



Collaboration Institutions

大阪大学 OSAKA UNIVERSITY

RCNP 大阪大学 核物理研究センター

福井大学 UNIVERSITY OF FUKUI

徳島大学 The University of Tokushima

大阪産業大学 OSAKA SANGYO UNIVERSITY

佐賀大学

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