First result of the CANDLES III experiment searching for double beta decay of ^{48}Ca

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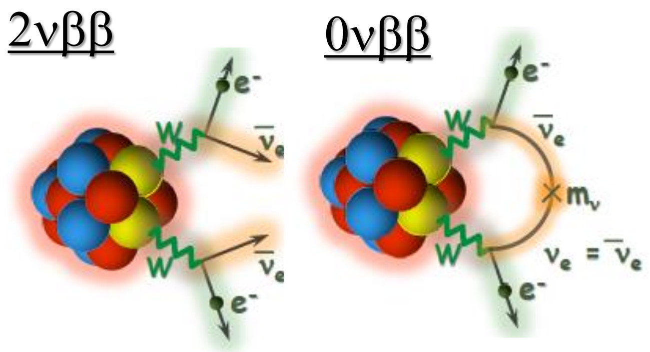
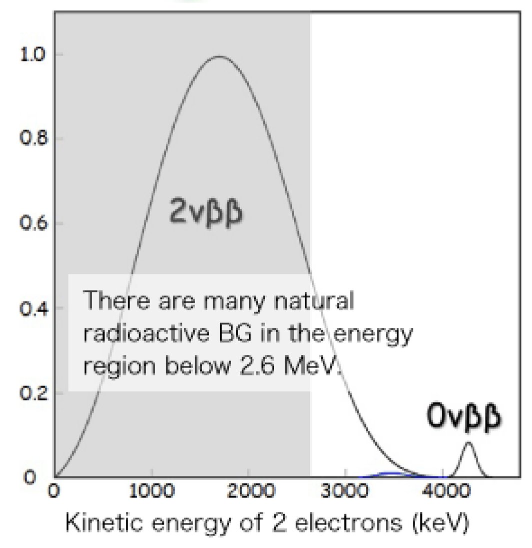
Double beta decay



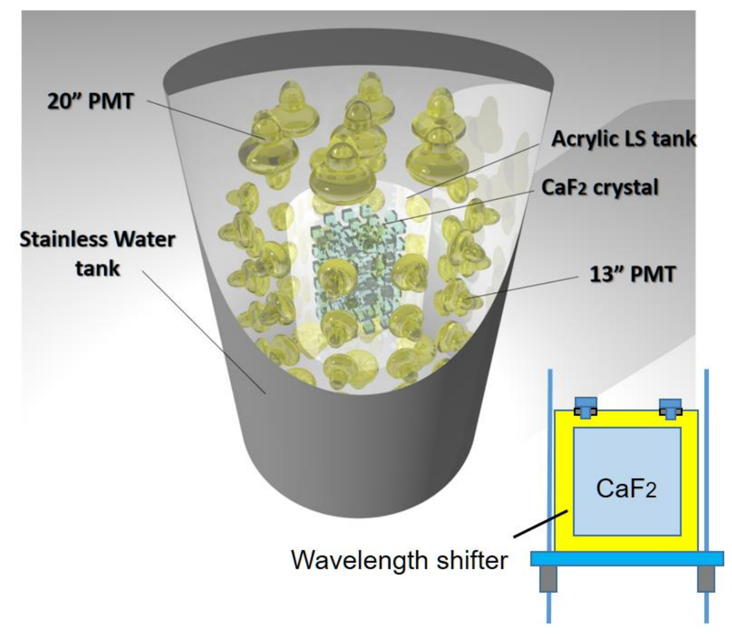
- **Neutrino less double beta decay (0νββ)** occurs when neutrino is Majorana particle.
- observation of 0νββ would proves;



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

- 0νββ has a peak at Q-value.
- Since 0νββ is extremely rare phenomenon, low background (BG) condition is important.

The CANDLES detector



CANDLES aims to perform the world's most sensitive 0νββ search by studying ^{48}Ca.

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

- 96 pure CaF_2 crystals (305kg)
- 62 photo-multipliers (13" & 20" PMTs)
- Light yield = 1,000 [p.e./MeV]
- 4π active shield※ by liquid scintillator (LS)

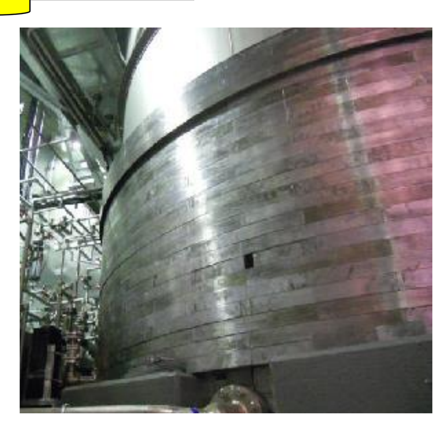
※Time const. = 1μs for CaF_2 / ~20ns for LS

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

[1] T. Iida et. al., Journal of Physics: Conference Series 718 (2016) 062026

Recent progress

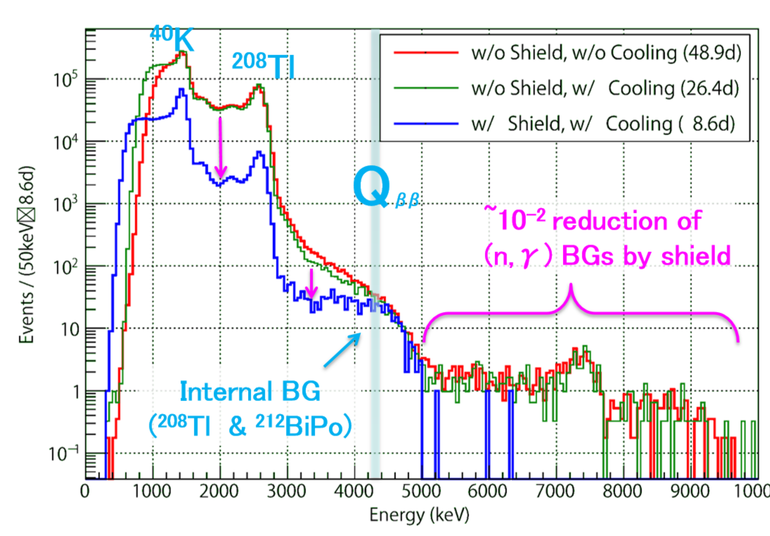
Shield construction for BG reduction



When thermal neutrons are captured in rich material surrounding the detector such as rock and stainless steel tank, high energy γ-rays are emitted so called (n,γ), e.g. 7.6 / 9.0 MeV of Fe / Ni [2].

- We constructed shield against (n,γ) reaction on rock and stainless tank in 2016.
- The shield is consist of Pb blocks (7~12 cm thickness) and Si rubber sheet containing 40 wt% of B_4C.

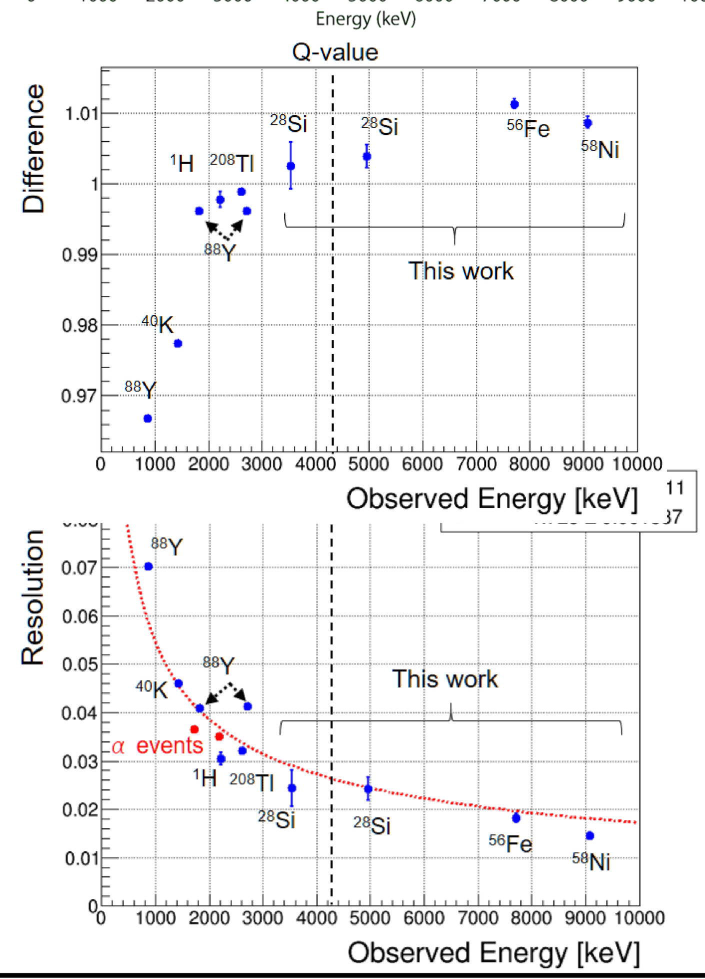
After installation of the shield, (n,γ) BG level has been reduced by two order of magnitude as shown in the right figure.



[2] K. Nakajima, T. Iida et. al., Astroparticle Physics, Volume 100 (2018), Pages 54-60

Energy calibration

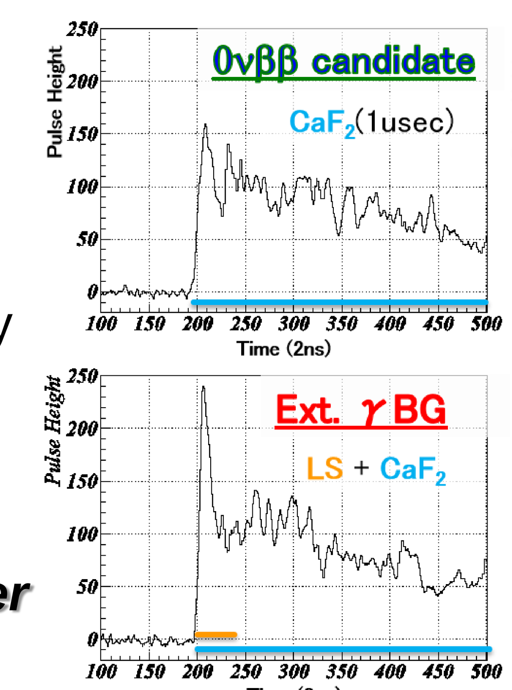
- Gamma-ray from neutron capture on nucleus (Fe / Ni / Si etc.) can be a good calibration source around ^{48}Ca Q-value of 4.27 MeV.
- We have developed high energy gamma ray calibration source by means of γ-ray from neutron capture reaction on various nuclei.
- **Good linearity and resolution** are obtained using this new calibration system in CANDLES.



	Results
Energy scale uncertainty	< 0.4% @4.27 MeV
Energy resolution	2.6% @4.27 MeV

0νββ search result

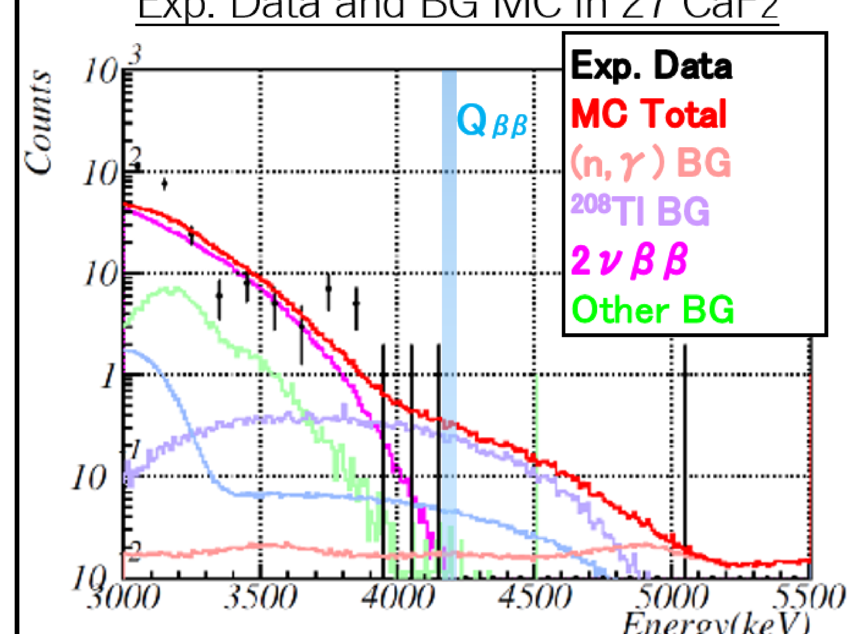
- **0νββ search** was conducted in region of interest corresponding to –1 sigma +2 sigma from Q-value.
- Crystals whose radio impurity of Th chain less than 10 μBq were selected.
- Other background were rejected analytically as follows.



- ☐ External gamma ray BG whose LS deposit > 150 keV were rejected by pulse shape discrimination method (see right figures).
- ☐ β+γ event of ^{208}Tl (Q value = 5MeV) was rejected using delayed coincidence method by tagging parent ^{212}Bi alpha decay.
- ☐ ^{212}Bi-^{212}Po sequential decay were rejected using waveform information.

$T_{1/2}$ > 6.2 ×10^{22} year was obtained as a upper limit of ^{48}Ca double beta decay half-life.

Exp. Data and BG MC in 27 CaF2



Preliminary result!!

	95 CaF2	27 CaF2 ※
Livetime	131	
0νββ eff.	0.39 ± 0.06	
Event in ROI	10	0
Expected BG	~11	~1.2
$T^{1/2}_{0\nu\beta\beta}$ ^{48}Ca (yr)	>3.8x10^{22}	> 6.2x10^{22}
Sensitivity (yr)	6.2x10^{22}	3.6x10^{22}

※ Th chain < 10 μBq/kg

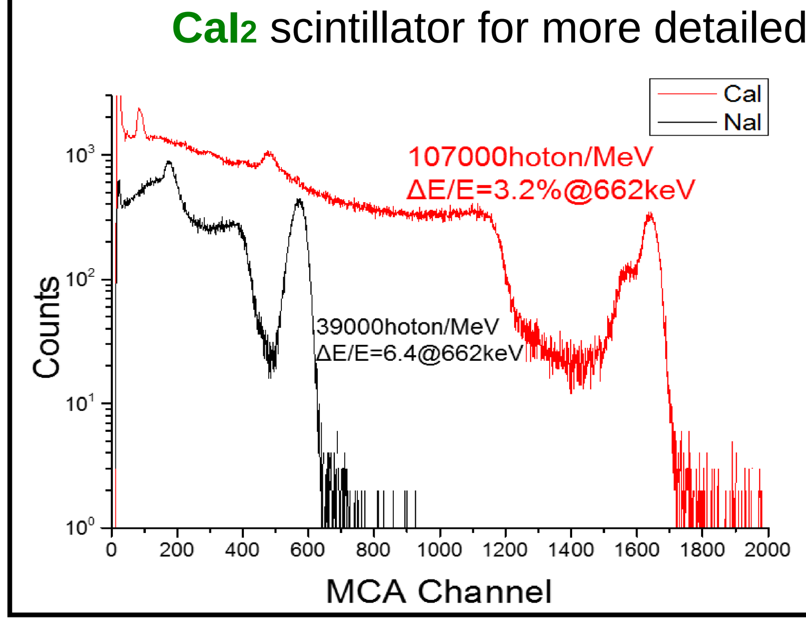
CANDLES is now leading frontier of ^{48}Ca double beta decay experiment !!!

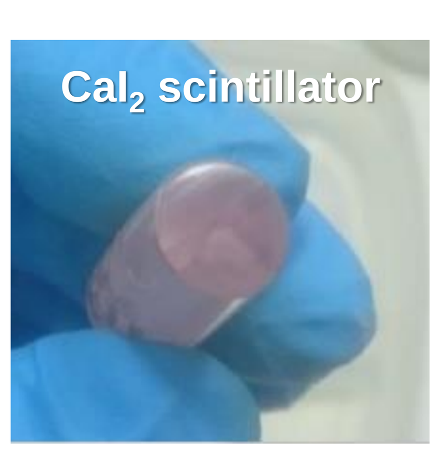
Study for future

*I'm trying to develop **CaI_2 scintillator** independent from CANDLES for future dark matter and 0νββ search [3].*

Calcium Iodide (CaI_2) scintillator

- CaI_2 is an inorganic scintillator whose light yield is larger than NaI(Tl) scintillator commonly used in this field.
- I successfully developed a crack free CaI_2 scintillator crystal collaborating with IMR in Tohoku University.
- **Obtained light yield was 2.7 times larger than NaI(Tl) and 10 times larger than CaF_2!!**
- Good energy resolution, **3.2% @662keV,** was achieved.
- **Next, construct a proto-type detector with a few kg of CaI2** scintillator for more detailed performance study.





Merit and Demerit of CaI2

☺ Merit

- ✓ High light yield → 2-3 times larger than NaI(Tl)
- ✓ Large WIMP cross section → $\sigma_{SI} \propto A^2$ (A=127 for I)
- ✓ No activator or wave length shifter (e.g. Eu, Tl) → High attenuation length & Easy enlargement ?
- ✓ Cheap → CaI2 is even used for dog food!

☹ Demerit

- ✓ High cleavable property (weak for shock)
- ✓ Strong deliquescence (weak for humidity)

Summary table of scintillator performance

	NaI(Tl)	CaI2
Light yield	39,000 ph/MeV	107,000 ph/MeV
E resolution	6.4% @662keV	3.2% @662keV
Emission WL	420 nm	410 nm
Time constant	230 ns	834 ns
Density	3.67 g/cm3	3.97 g/cm3

[3] K. Kamada, T. Iida et al., Ceramics International, Vol. 43, suppl. 1 (2017), Pages S423-S427

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New collaborator is wanted !!!