Search for Neutrino-less Double Beta Decay in CANDLES Ⅲ+ experiment

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Neutrino-less double beta decay ($0\nu\beta\beta$) is a very unique nuclear process, where the conservation of lepton number is violated under the light Majorana neutrino exchange. Observation of the process will uncover the neutrino mass hierarchy through the effective neutrino mass $\langle m_{\beta\beta}\rangle \equiv \left|\Sigma_i U_{ei}^2 m_{\nu_i}\right|$, the square of which is proportional to the decay rate. Furthermore it could refer to the formation of the current matter-dominated universe via the description of the leptogenesis.

CANDLES experiment is a $0\nu\beta\beta$ search experiment utilizing ^{48}Ca as decay nuclei, which have the highest expected energy among various $0\nu\beta\beta$ nuclei, monochromatic 4.3 MeV. Due to the high energy, ^{48}Ca has the superiority for the search of extremely low rate $0\nu\beta\beta$ decays since the most of the background from the radio-impurities in the surrounding materials have lower energies.

CANDLES Ⅲ experiment has been run at the underground observatory in Kamioka, Hida-city. As in Figure. 1, the detector consists the 96 CaF_2 crystal scintillators, immersed in the liquid scintillator (LS), which works as a 4π active shield to external backgrounds. The emitted photons from the scintillator are observed by 62 photomultipliers tubes (PMTs) and the origin is discriminated by their signal length. (∼10ns for LS, ∼ μs for CaF_2).

For the latest data acquisition, we have two major upgrades studied since 2014. Hence we call the new version as CANDLES Ⅲ+. The first one is the neutron and γ-ray shield. In the previous data, substantial high energy γ-rays from neutron captures (n, γ) on nuclei (e.g. ^{56}Fe, ^{58}Ni, ^{28}Si) inside the surrounding rock and the metal material were observed. Lead blocks of 7cm thick, which were reinforced to 12 cm thick at the sensitive side part were piled up for shielding external γ rays, and 5mm thick boron sheets were put on the surface of the main water tank and outside the lead blocks for absorbing neutrons. The structure is also shown in Figure. 1. The reduction factor of γ-rays were expected to be ∼ 1/80, while the observed reduction factor using ^{252}Cf is evaluated to be ∼ 1/70. The observed background energy spectrum is shown in Figure. 2 (shown in blue). In comparison to the data without shielding (shown red and green), background reduction above 5 MeV is evident. The reduction factor is ∼ 1/35.5, which is evaluated with merely 3 events for the successfully strong shielding.

The second is the two techniques for higher light collection by the PMTs. One is the geomagnetic compensation coils. The magnetic field generated from the coil surrounding whole detector side, where 1.6A current is running, compensates the distorted photo-electron flight then increased the light collection by 30%. The other is the cooling. It is known that a CaF_2 scintillator emits +2% light for 1°C reduction at around room temperature. The detector has been operated at 5.0±0.2°C, where the light yield has increased by ∼23%.

The latest data acquisition at the shielded and chilled status was started in July 2016 and has been monitored with periodical ^{88}Y (1.8MeVγ) source calibration. We expect an update on the $0\nu\beta\beta$ rate limit for ^{48}Ca with one-year data taking.

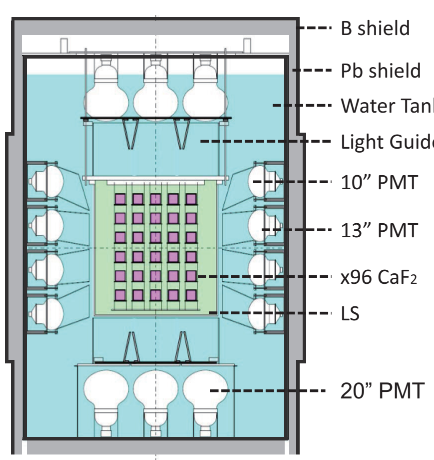

Figure 1:
CANDLES Ⅲ+ detector.
Detector size is 3mϕ, 4m tall.

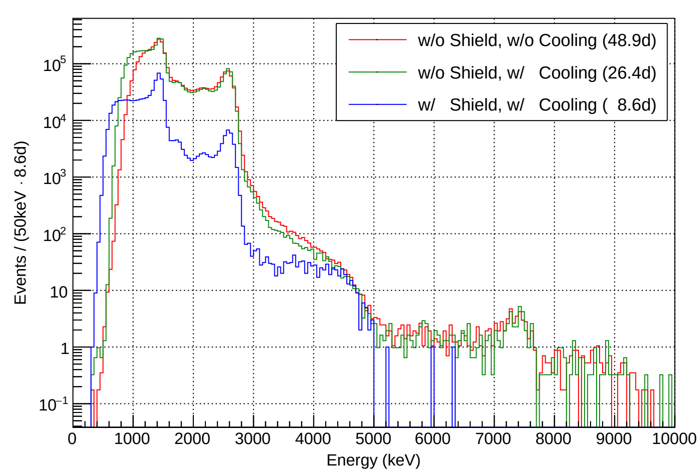

Figure 2: CANDLES Ⅲ+ background spectrum in the earlier time in 2016 (blue). (n,γ) background reduction above 5 MeV is evident. Lower energy γ bacgrounds from ^{208}Tl and ^{40}K are also reduced.