1. Introduction

The XMASS project:
- A multi purpose experiment using liquid xenon (LXe) located 1,000 m underground (2,700 m.w.e.) at the Kamioka Observatory in Japan.
- Aiming for
  - Direct detection of dark matter
  - Observation of low energy solar neutrinos (p+p/Be)
  - Search for neutrino-less double beta decay
- Features:
  - Low energy threshold
  - Sensitive to e/γ events as well as nuclear recoil
  - Large target mass and its scalability

XMASS has challenged various topics in neutrino physics

2. Search for two-neutrino double electron capture on $^{124}$Xe and $^{126}$Xe

Double electron capture (ECCE):
- Two orbital electrons are captured simultaneously
- The 2ν mode is allowed within the Standard Model, but there are only two possible results so far (99g, 136Ba).
- The 0ν mode would be evidence of Majorana neutrino.
- $^{124}$Xe (N.A. = 0.09%) and $^{126}$Xe (0.089%) are the candidates.
- $^{124}$Xe 2ν-ECCE from K-shell (2eX)/2K
  - $^{124}$Xe + 2ν → $^{124}$Te + 2ν$_{e}$ (Q=2864 keV)
  - Only X-rays/Auger electrons are observable
  - Total energy deposit is $-2E_{\text{Xe}}$ = 63.6 keV
- Theoretical prediction $T_{2\nu}=10^{10}$-10$^{14}$ years
- Previous limit $T_{2\nu}>4.7\times10^{13}$ years (90%CL)


Improved analysis using the XMASS-I data:
- New data (Nov 2013-Jul 2016) taken after detector refurbishment
  - Livetime: 132.0 days → 800.0 days
  - Fiducial mass: 41 kg (29 g of $^{124}$Xe) → 327 kg (311 g of $^{124}$Xe)

- Developed particle identification using scintillation time profile
- Scintillation decay time depends on electron kinetic energy.
  - $^{124}$Xe: Kinetic energy $\theta_{\text{kin}}$ depends on e- energy $E_{\gamma}$.
  - $^{124}$Te: $\theta_{\text{kin}}$ depends on e- energy $E_{\gamma}$.

It allows us to separate β-ray (single electron) vs. X-ray/γ-ray (multiple e)
- 2e2K (two X-rays)
- Data vs. MC

- A parameter (I_CL) is constructed from each PE’s timing
  - under the hypothesis that the event is caused by a β-ray.

- If I_CL<0.05 is selected, S/N improves by a factor of 5.
- Performed spectrum fitting with a detailed BG evaluation
  - Internal BG: $^{214}$Rn (Bi, Pb), $^{137}$Cs, $^{85}$Kr, $^{124}$Xe and $^{136}$Ba.
  - $^{124}$Xe is produced by thermal neutron capture on $^{124}$Xe outside the water shield.
  - Fitted 3 sub-samples x 4 periods, simultaneously

- GL: confidence level (or p-value) of each PE timing

3. Search for neutrinos from supernova (SN) or gravitational-wave (GW) events

Coherent elastic neutrino-neutrino scattering (CEvNS):
- Neutrino is scattered off by all the nucleons in a nucleus coherently
  - Weak neutral current interaction
  - Cross section: $N^2$ (K number of neutrons)
  - Recal energy: $\sim$10 keV

- New way to detect SN neutrinos
  - Mechanism of neutrino trapping in the SN core
  - Ultimate background for direct dark matter searches

Possibility to detect galactic SN neutrinos via CEvNS in XMASS-I

Search for event bursts in XMASS-I associated with GW events:
- Several GW events have been reported by LIGO and Virgo so far
- Recently, a GW event from a binary neutron-star (NS) merger (GW170817) was detected with electromagnetic counterparts.
- There are some theoretical predictions of neutrino emission from binary NS mergers.

- Model independent event burst search for GW170817
  - Simple event selection using the full 832-kg LXe target
  - Divided into 4 energy regions
  - Looked for bursts in a sliding time window with various widths
  - No significant event burst was found in $400-10^{10}$ s or $10^{10}$ s.

Limits on neutrino fluence from GW170817
- We set 90%CL upper limits on neutrino fluence for sum of all neutrino flavors via CEvNS.
- Limits are calculated for mono-energetic neutrinos with energy between 14 and 100 MeV.

- Black: limits from the on-time window
- Blue: limits from the $<400-10^{10}$ s <400 window

5. Summary

- The XMASS-I detector has been stably taking data for more than 4 years, and will continue data-taking until December 2018.
- Thanks to low energy threshold, low background, and large target mass, XMASS has a potential to pursue various topics in a field of neutrino physics.
- Searched for double electron capture on $^{124}$Xe and $^{126}$Xe → The most stringent lower limits on half-lives were derived.
- Investigated a possibility to observe supernova neutrinos via CEvNS → We are waiting for the next supernova in the Galaxy.
- Searched for event bursts associated with gravitational-wave events → Limits on neutrino fluence from GW170817 was derived.