

Search for neutrinos  
from BNS merger: GW170817 with KamLAND

# KamLANDを用いた 中性子星連星合体由来の ニュートリノ探索

低エネルギー

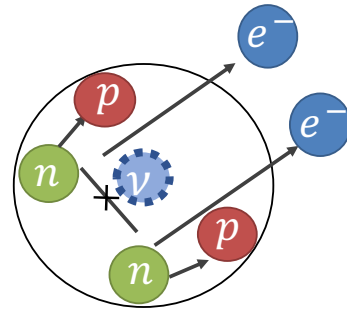
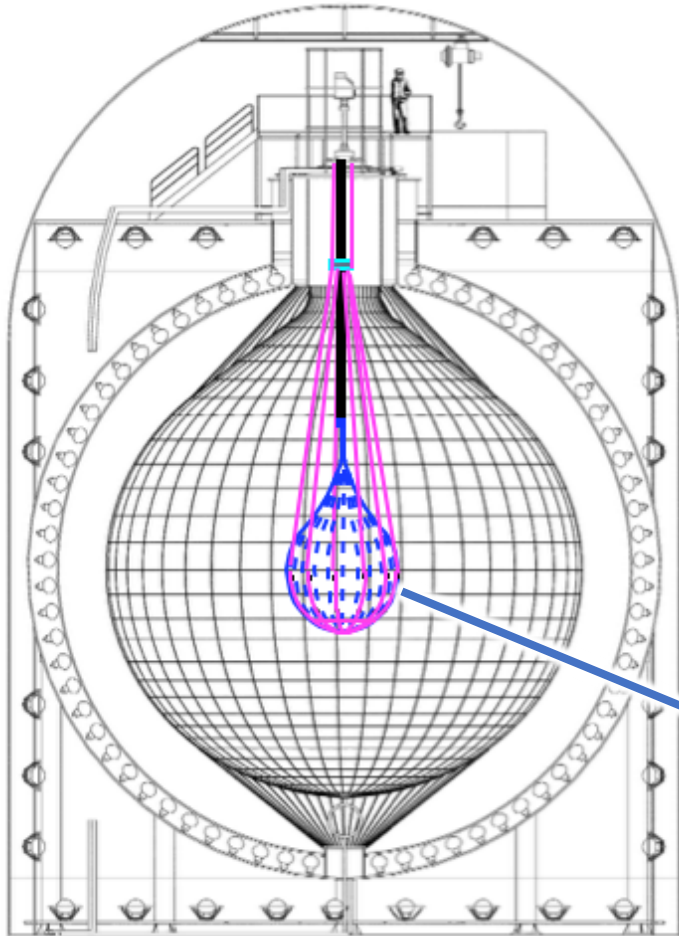
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RCNS, Tohoku univ.

超新星ニュートリノ研究会

1/8—1/9, 2018@強羅静雲荘

# My activities



Miniballoon construction for KamLAND-Zen 800:  
neutrinoless double beta decay search.

I'm leading

- Welding
- Leak-repairing
- Reinforcement of welded part

Analysis

- MeV “single event” physics
  - $0\nu\beta\beta$
  - ${}^8\text{B}$  solar
  - Positronium\*
- Spallation BG reduction

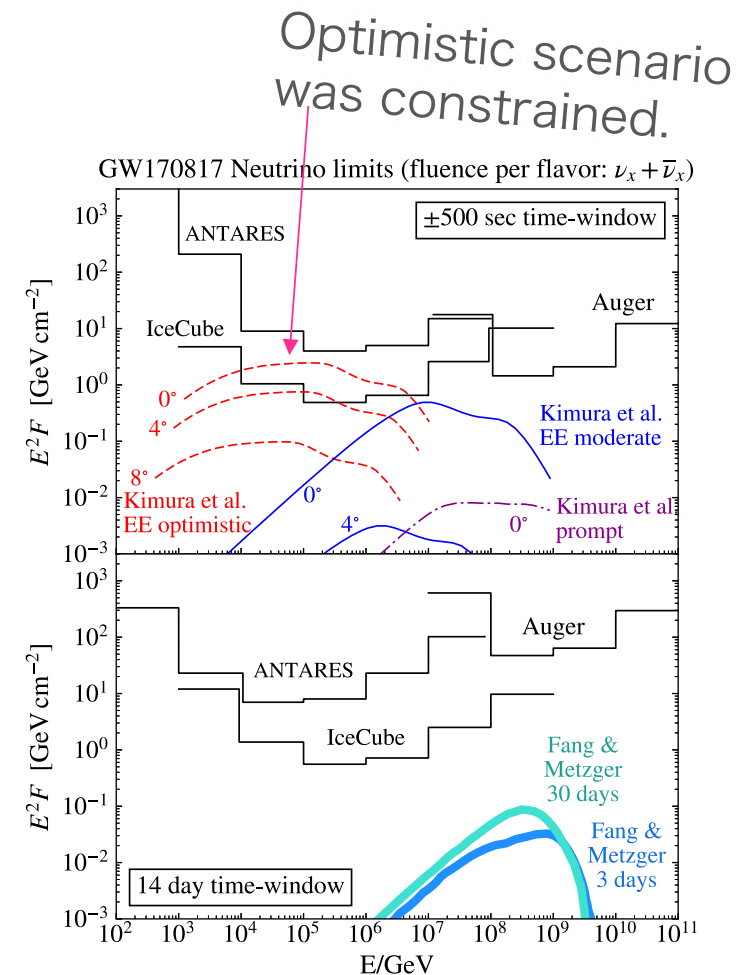


Now final stage of leak-repairing.

Sorry,  
this time I cannot show the final results...

# GW170817 and $\nu$ observatory follow-up

- **GW170817 (GRB 170817A)** ApJ Lett., 848:L12, 2017
  - **Multi-messenger detection** of Binary Neutron Star(BNS) merger.
  - Luminosity distance: 40 Mpc
  - Radiated energy  $> 0.025 M_{\text{solar}} \sim 4.5 \times 10^{52}$  erg
  
- No high energy neutrino (GeV—EeV) was found by ANTARES, IceCube, and PAO. ApJ Lett., 850:L35, 2017
  
- MeV neutrino wasn't observed by **IceCube's noise rate**.
  - Corresponds to anti- $\nu$  luminosity  $< \sim 10^{59}$  erg(?) ApJ Lett., 850:L35, 2017
  - A&A 535, A109 (2011)



# BNS merger and thermal $\nu$ emission

## Thermal $\nu$ from BNS merger

- T gets to O(10) MeV after merger
  - $e^-/e^+$  pair creation, capture on nuclei  
 →  $\nu_e$ / anti- $\nu_e$  emission.
    - ✓ more anti- $\nu_e$  due to neutron richness.
  - $\nu_x$  from annihilation
  - Energy: O(10) MeV

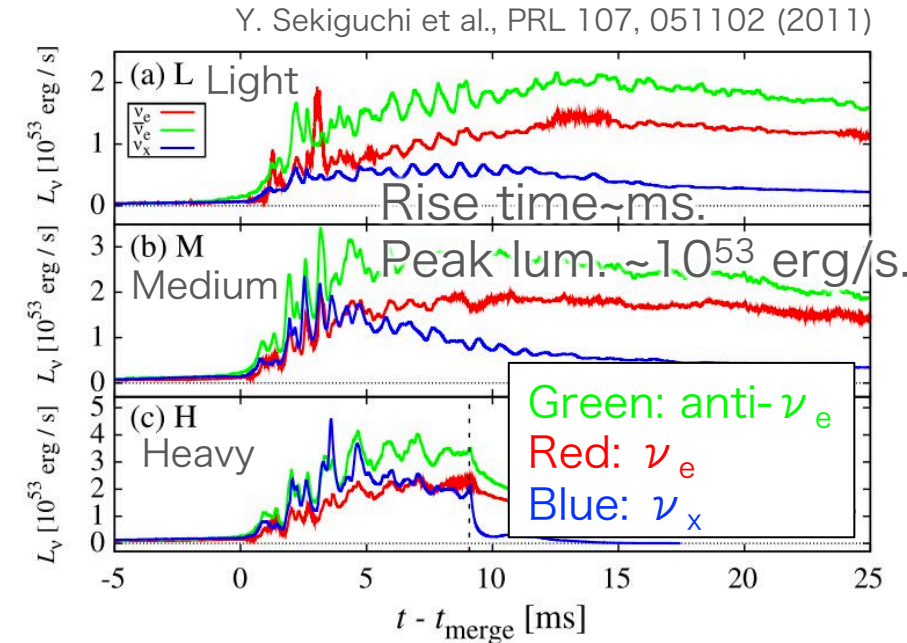
## Thermal $\nu$ detection

K. Kyutoku, K. Kashiyama, arXiv:1710.05922

- Motivation
  - Constraint energy via  $\nu$  emission.
  - $\nu$ -mass measurement by time diff. from GW.

○  $\sim 3 \times 10^{52}$  erg anti- $\nu_e$  emission  
 (Integrated over 1 sec)

○ Exposure of 80 Mt\*yr is necessary...



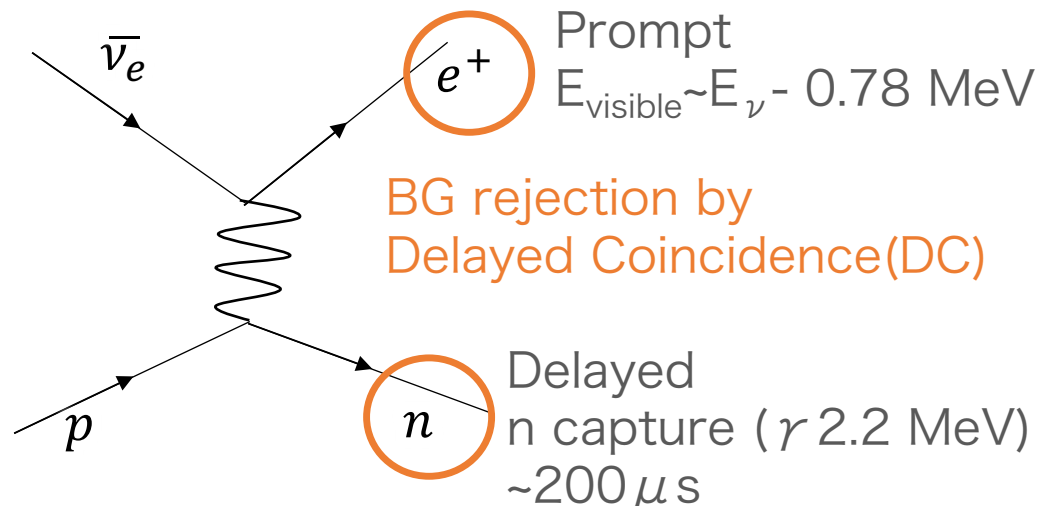
$$\Delta t \sim 0.51 \text{ s} \left( \frac{D}{100 \text{ Mpc}} \right) \left( \frac{m_\nu}{100 \text{ meV}} \right)^2 \left( \frac{10 \text{ MeV}}{E_\nu} \right)^2$$

$$N_\nu \approx 1.0 \times 10^{-3} \times f_E f_{se} f_{osc} \left( \frac{M_T}{1 \text{ Mt}} \right) \left( \frac{E_{\Delta t}}{3 \times 10^{52} \text{ erg}} \right) \times \left( \frac{\langle E \rangle}{10 \text{ MeV}} \right) \left( \frac{D}{100 \text{ Mpc}} \right)^{-2}. \quad (6)$$

# $\nu$ detection methods

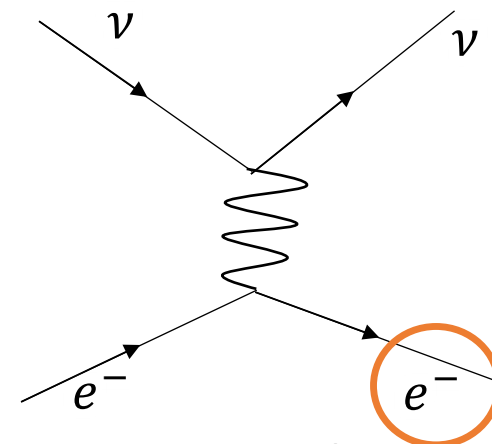
## Invers Beta Decay (IBD)

- anti- $\nu_e$  only
- $E_\nu$  reconstruction
- Reaction threshold 1.8 MeV
- Cross section higher than ES



## Electron Scattering (ES)

- Sensitive to all  $\nu$  (especially  $\nu_e$ )
- $E_\nu$  cannot be reconstructed.
- No threshold
- Directional info. (not in Liquid Scint.)

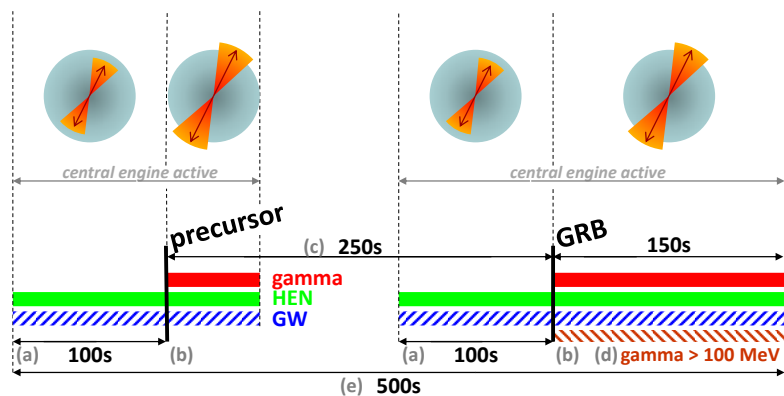


# Ref.: Limits on $\nu$ from BBH merger

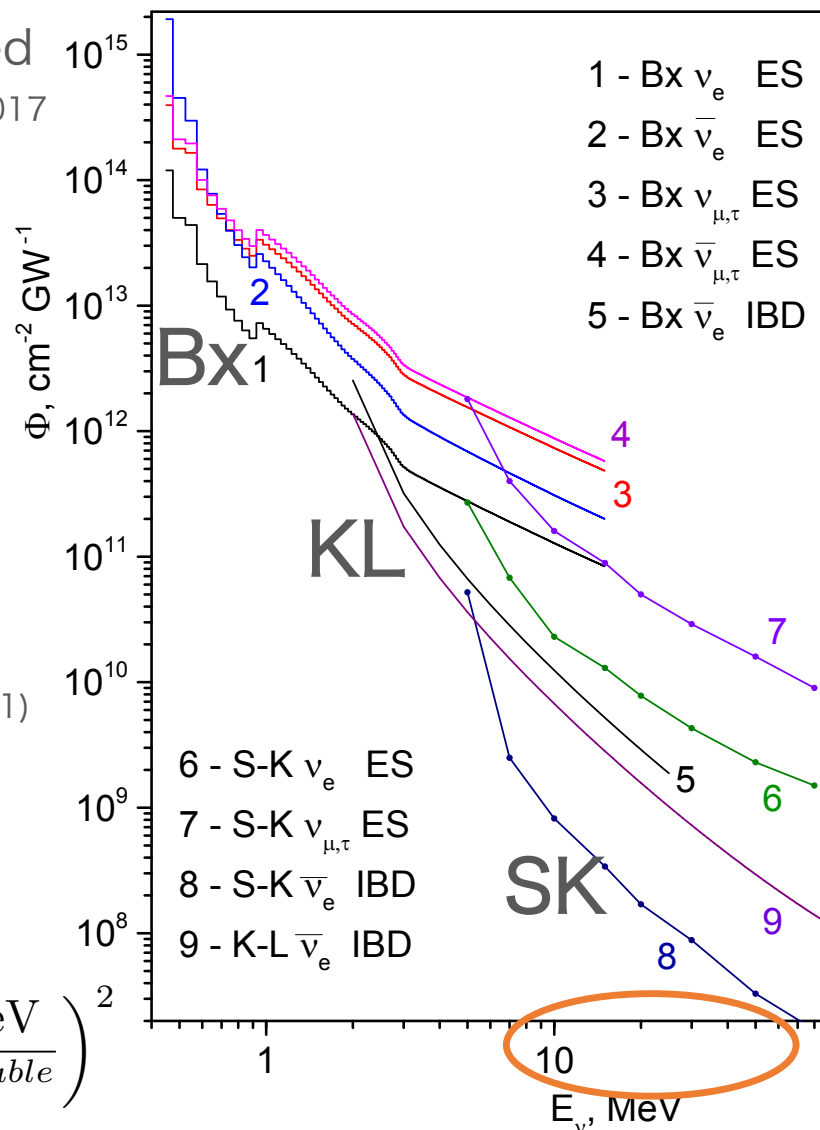
Mono-energetic  $\nu$  assumed

ApJ 850:21, 2017

+/- 500 sec window searched



B. Baret et al., Astropart. Phys. 35, 1 (2011)



(Bx: Borexino)

- SK good at expected thermal  $\nu$  region.
- KamLAND good below 5 MeV.

Too much for thermal  $\nu$ ?

- Peak emission  $dt < 1$  sec
- TOF not so long.

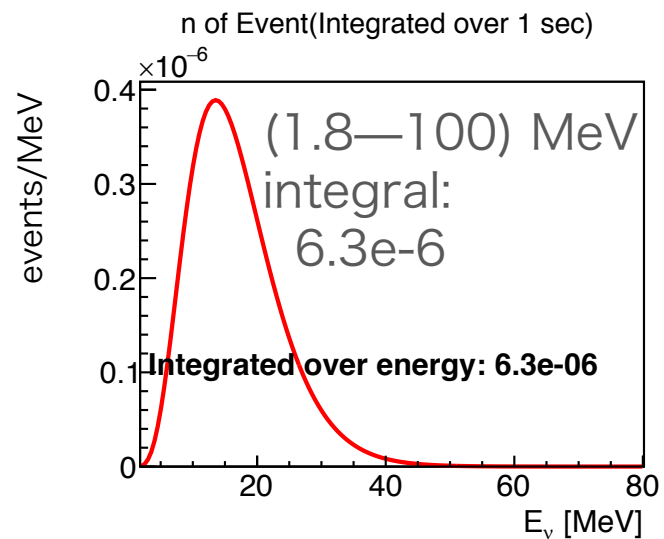
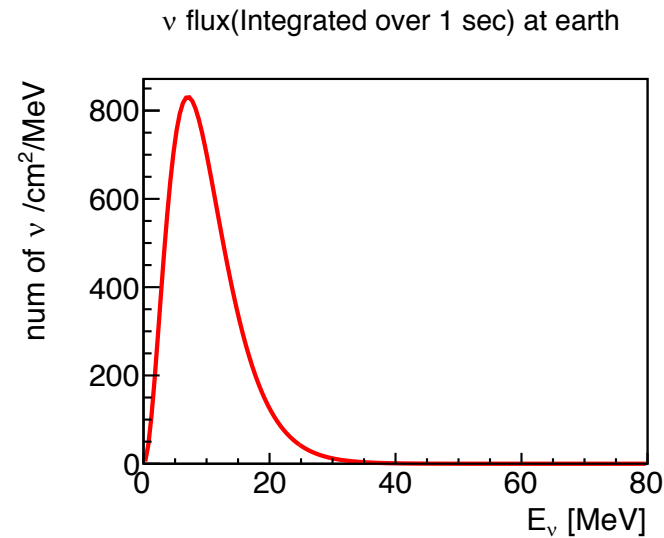
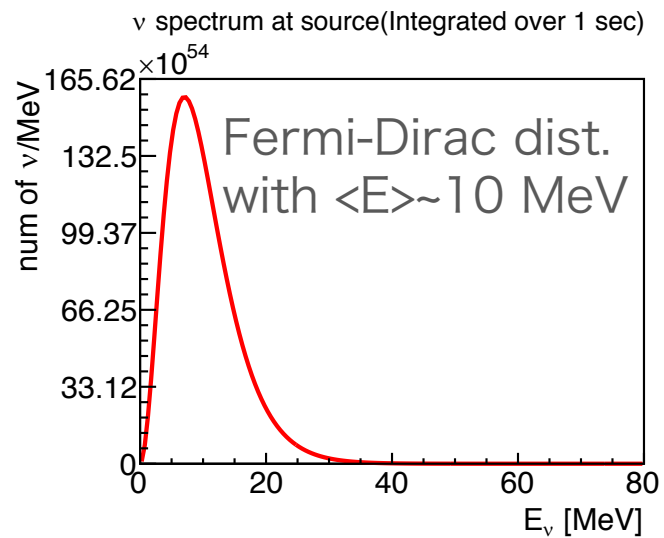
$$\text{Window} = 10 \text{ s} \left( \frac{m_{\nu}^{\text{heaviest}}}{70 \text{ meV}} \right)^2 \left( \frac{1.0 \text{ MeV}}{E_{\nu}^{\text{detectable}}} \right)^2$$

(40 Mpc)

# expected @KamLAND



# #IBD expected ( $\langle E \rangle \sim 10$ MeV)

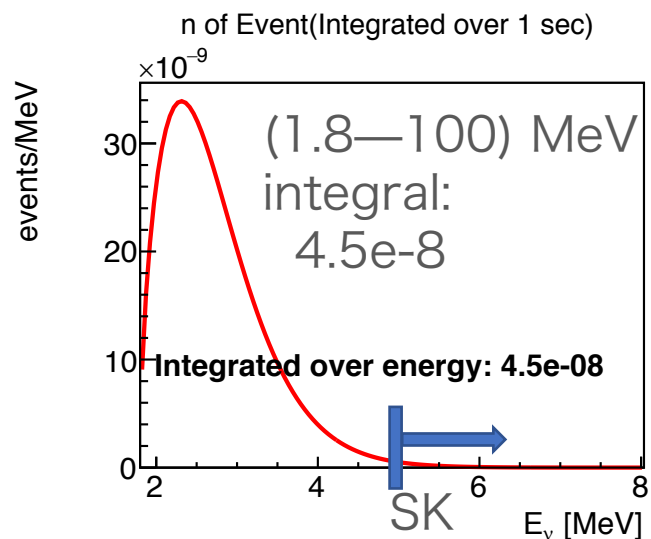
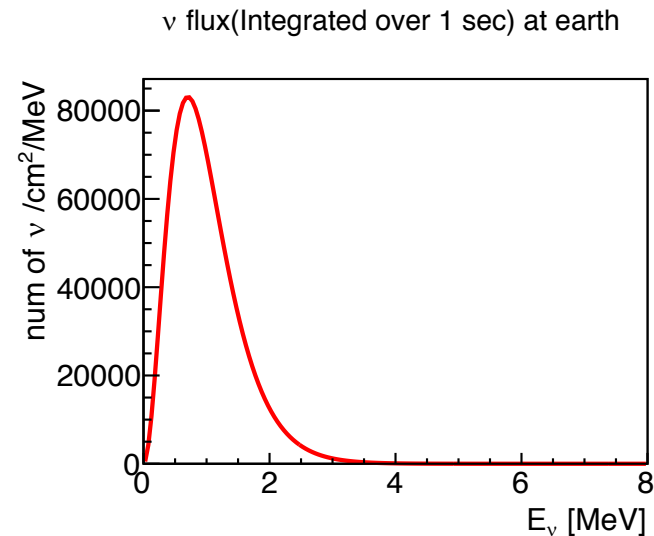
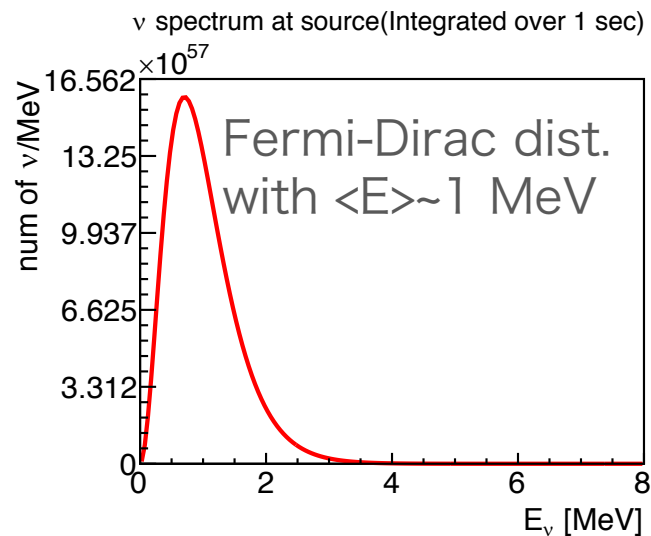


## Assumptions:

- Anti- $\nu_e$  luminosity:  $3e52$  erg
- Oscillation not included.
- #proton:  $6.0e31$  (KamLAND R6-m fiducial)
- 1.8 MeV threshold.

$\sim 10^{57}$  erg upper limit if BG free.

# #IBD expected ( $\langle E \rangle \sim 1$ MeV)

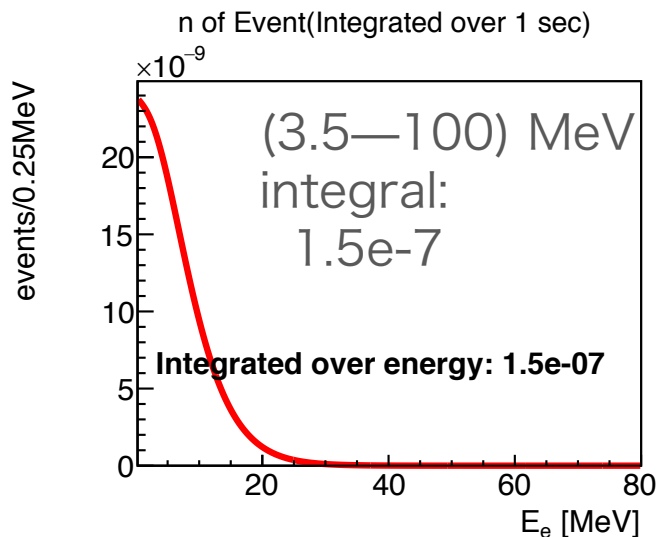
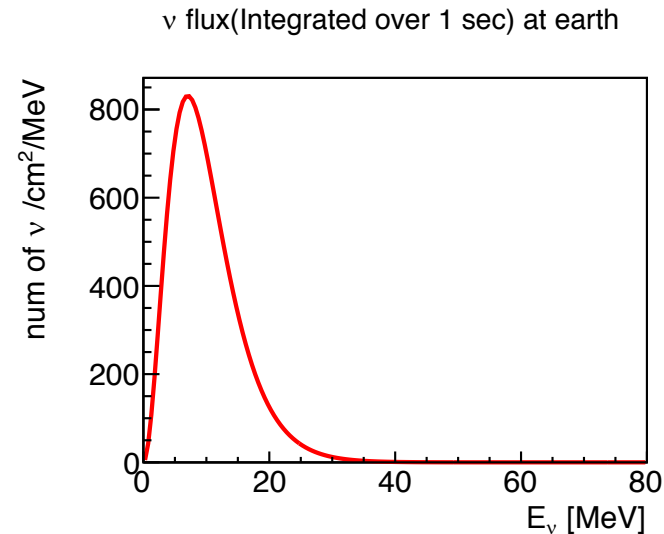
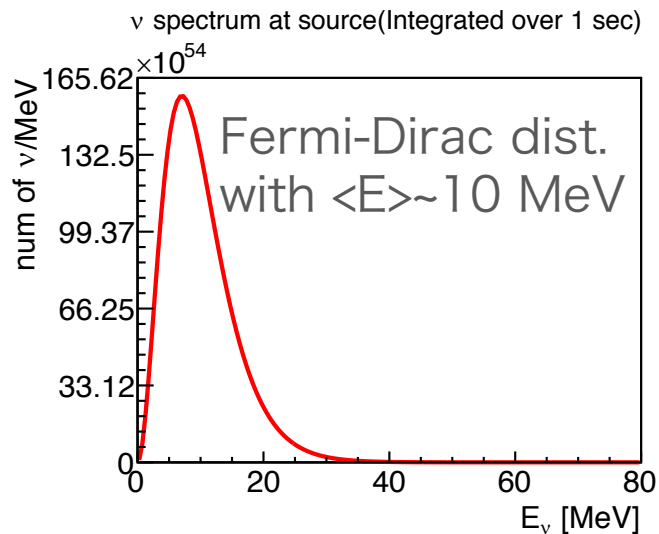


## Assumptions:

- Anti- $\nu_e$  luminosity:  $3e52$  erg
- Oscillation not included.
- #proton:  $6.0e31$  (R6-m fiducial)
- 1.8 MeV threshold

$\sim 10^{59}$  erg upper limit if BG free.

# #ES( $\nu_e$ ) expected ( $\langle E \rangle \sim 10$ MeV)



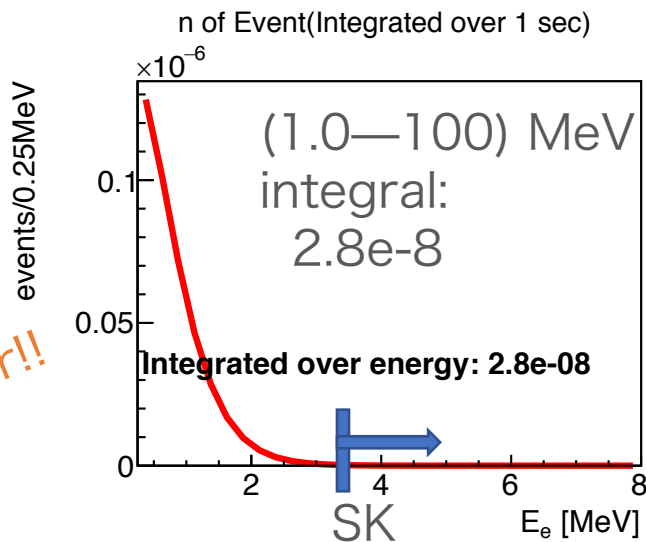
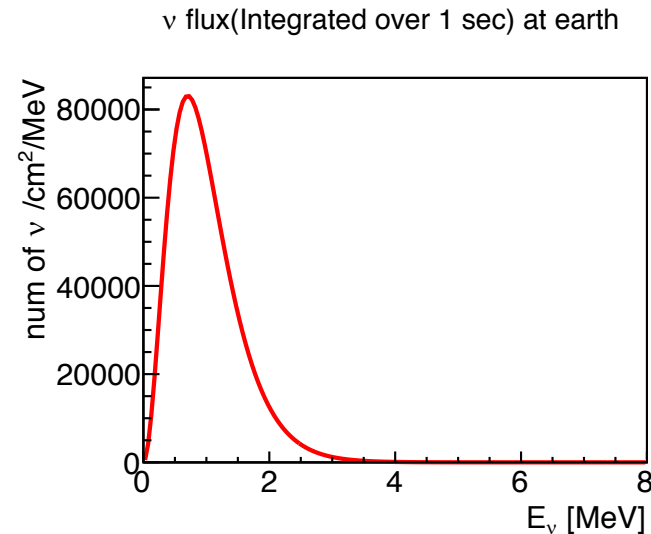
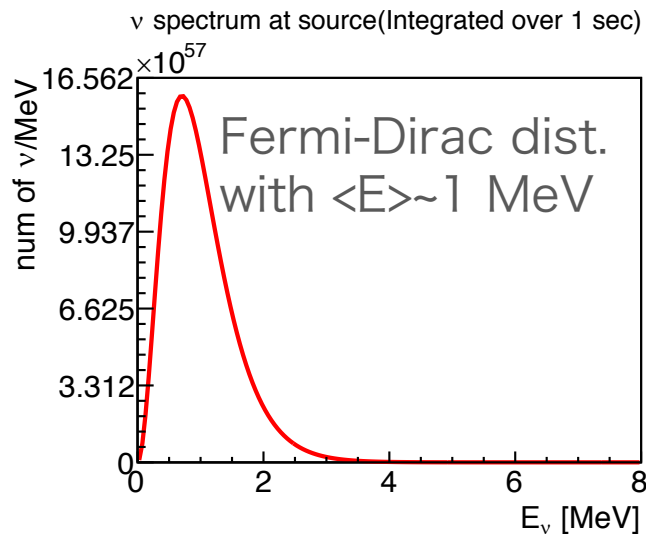
1/40 smaller than  
anti- $\nu_e$  IBD:  
6.3e-6

## Assumptions:

- $\nu_e$  luminosity: 3e52 erg
- Oscillation not included.
- #electron: 2.3e32 (R6-m fiducial)
- 3.5 MeV threshold

$\sim 10^{59}$  erg upper limit if BG free.

# #ES( $\nu_e$ ) expected ( $\langle E \rangle \sim 1$ MeV)



Almost same as  
anti- $\nu_e$  IBD:  
 $4.5e-8$

Pros of LS detector!!

## Assumptions:

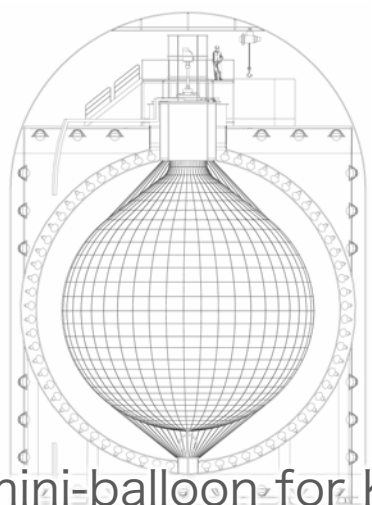
- $\nu_e$  luminosity:  $3e52$  erg
- Oscillation not included.
- #electron:  $1.3e32$  (R5-m fiducial)
- 1 MeV threshold

$\sim 10^{60}$  erg upper limit if BG free.

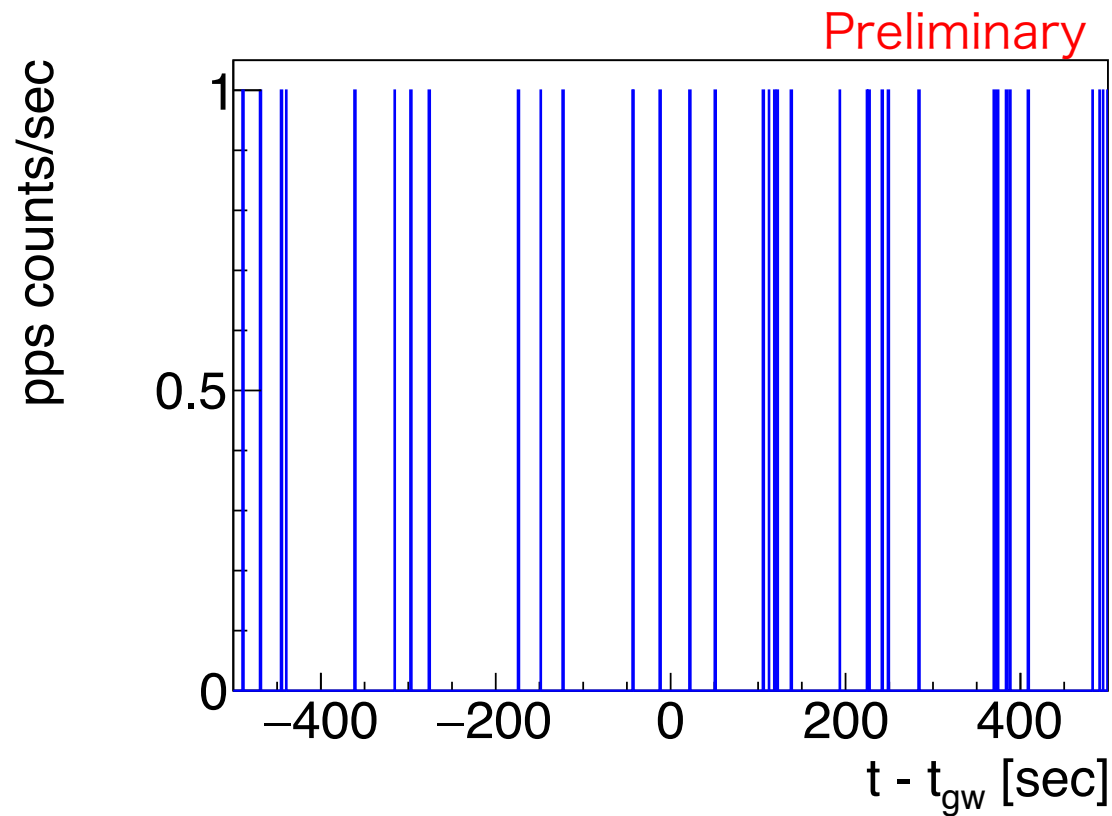
# DATA

Sorry, this time the window cannot be shown.  
BG situation only.

# Live time in the window



No mini-balloon for KL-Zen.  
Full volume available.



In-active time due to

- muon-spallation veto
- detector's deadtime

~90% active

# BG rate for IBD search

## Event selection

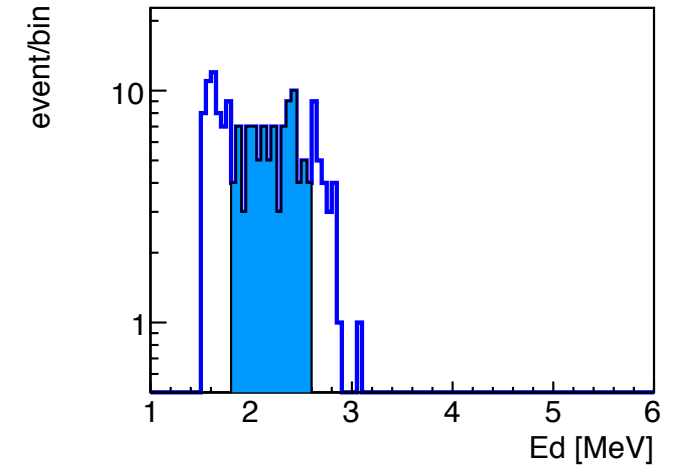
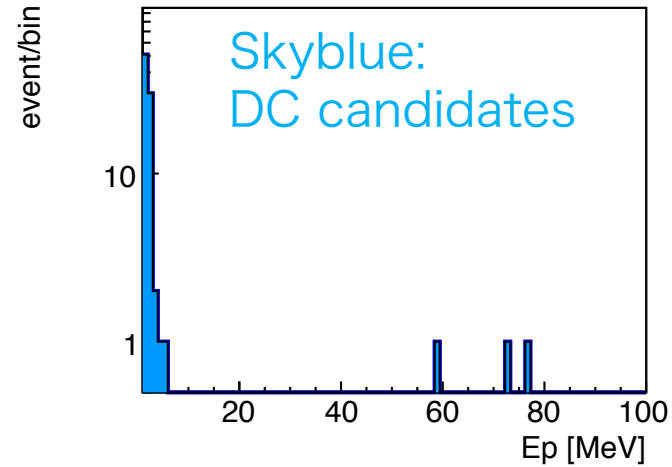
- 2017/8/1—2017/8/30  
(w/o 8/17): 24 livedays
- muon veto
- ~~likelihood cut~~

## Event rate:

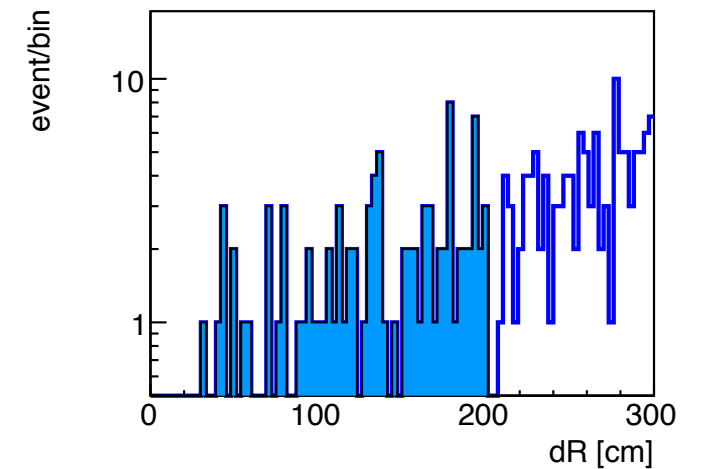
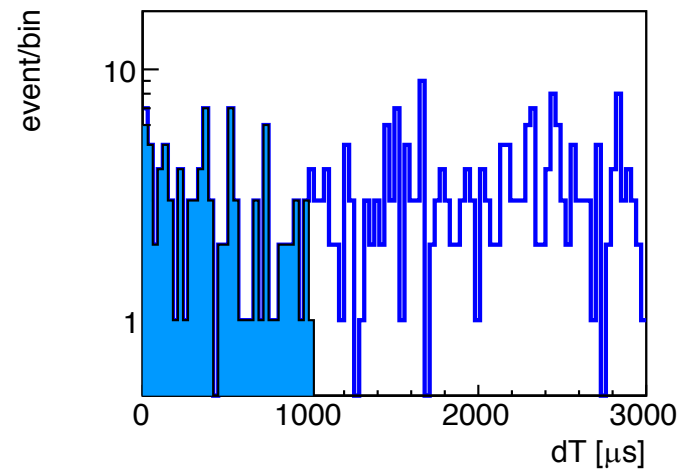
88 evts/24day ~  $4.2e-5$  evts/sec

- Almost all are accidental BG.
- **Negligible in 1000 sec window.**

## DC related parameters

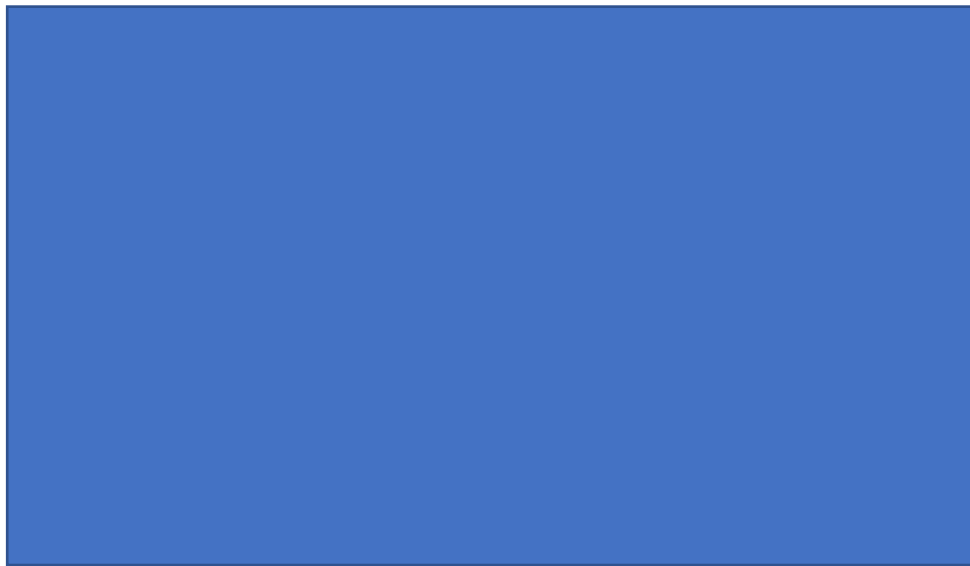


Preliminary



# BG rate for ES search

Energy spectrum

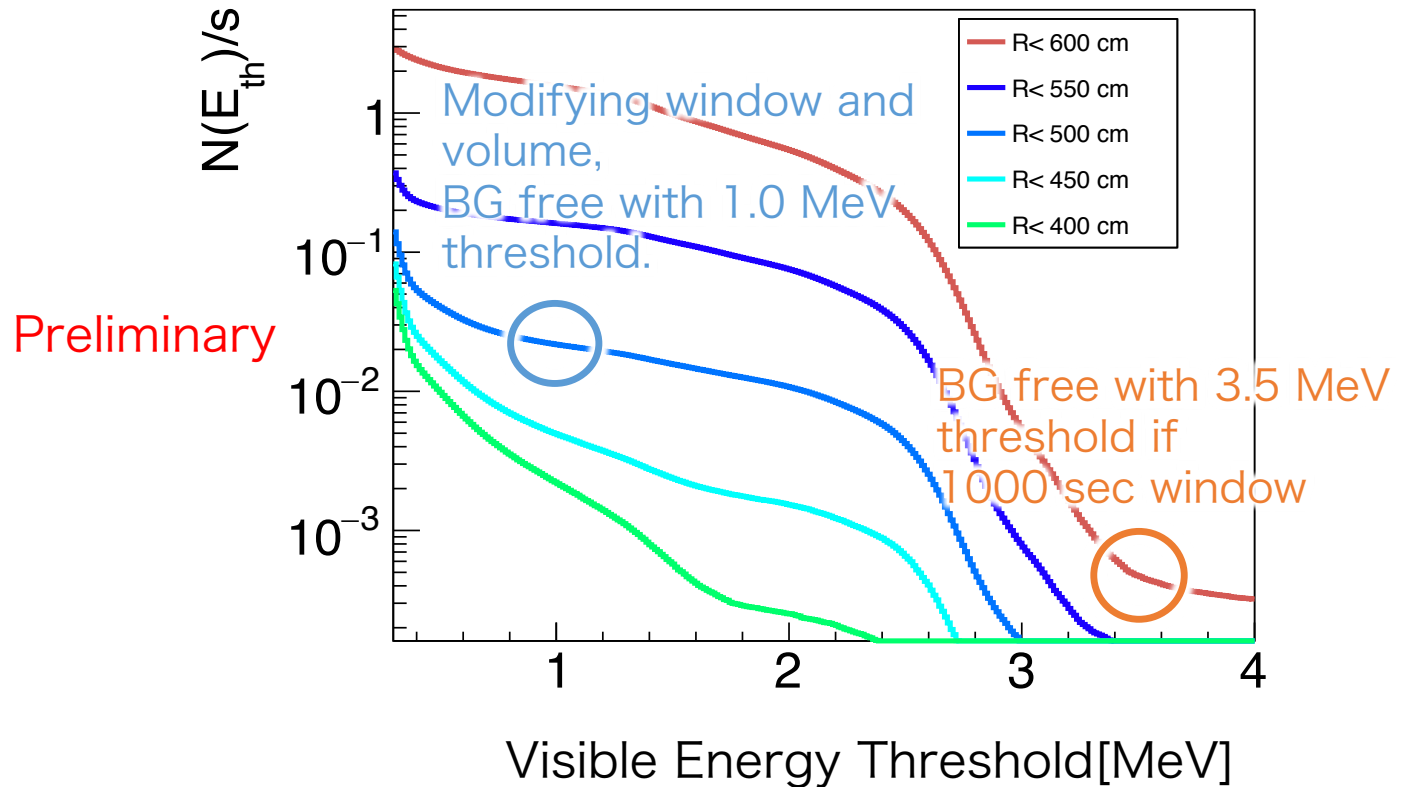


Visible Energy [MeV]

Event selection

- 2017/8/1—2017/8/30 (w/o 8/17): 24 livedays
- muon veto

Integrated BG rate



$$\text{Window} = 10 \text{ s} \left( \frac{m_{\nu}^{\text{heaviest}}}{70 \text{ meV}} \right)^2 \left( \frac{1.0 \text{ MeV}}{E_{\nu}^{\text{detectable}}} \right)^2$$



# Summary

- Search for MeV-neutrinos from BNS merger: GW170817 with KamLAND is ongoing.
- The detector was active at the merger without miniballoon.
- #Inverse Beta Decay expected:  $\sim 10^{-6}$ 
  - Sensitivity on anti- $\nu_e$  luminosity  $\sim 10^{57}$  erg
- #Electron Scattering( $\nu_e$ ) expected:  $\sim 10^{-7}$ 
  - Sensitivity on  $\nu_e$  luminosity  $\sim 10^{59}$  erg
- KamLAND good at  $\langle E \rangle \sim O(1)$  MeV region.
- Stay tuned for checking events in the coincidence window!!

# Backup

# MeV- $\nu$ detection by IceCube's noise rate

Ref. A&A 535, A109 (2011)

- Supernova (10kpc,  $3e^{53}$  erg) yields  $1.3e^5$  hits (integrated 0.8 sec, anti- $\nu_e$ ).
- Noise rate  $\sim (7E5 \pm 1E3)/0.5\text{sec} \sim (1.4E6 \pm 2E3)/\text{sec}$
- Limit rate  $\sim 4E4$
- Limit luminosity on GW170817  $\sim 1.5E^{59}$  erg

$$E_{\nu}^{detectable} = \frac{E_{th}}{2} \left( 1 + \sqrt{1 + 2 \frac{m_e}{E_{th}}} \right)$$