Search for correlated event with GW170817 in KamLAND

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KamLAND

o etc...

since 2002 <u>Kam</u>ioka <u>Liquid scintillator Anti-Neutrino Detector</u>



KamLAND-Zen 800

Zero neutrino double beta decay search



ν detection methods

Invers Beta Decay (IBD)

- anti- ν_{e} only
- E_{ν} reconstruction
- Reaction threshold 1.8 MeV
- Cross section higher than ES



Electron Scattering (ES)

- Sensitive to all ν (especially $\nu_{\rm e}$)
- E_{ν} cannot be reconstructed.
- No threshold
- Directional info. (not in Liquid Scint.)



GW170817 and ν observatory follow-up

 10^{3} ANTARES GW170817 (GRB 170817A) ApJ Lett., 848:L12, 2017 10^{2} $[GeV cm^{-2}]$ 10^{1} Multi-messenger detection of Binary Neutron Star(BNS) merger. IceCube 10^{0} $E^{2}F$ Luminosity distance: 40 Mpc 10^{-2} \circ Radiated energy > 0.025 M_{solar}~4.5x10⁵² erg 10^{3} • ΔM < 0.2—0.8 M_{solar} 10^{2} E^2F [GeV cm⁻²] ANTARES 10^{1} $\circ t_{GRB} - t_{GW} = 1.7 \text{ sec}$ IceCube 10^{0} 10^{-} No high energy neutrino (GeV—EeV) was found by ANTARES, IceCube, PAO, and SK. 14 day time-window 10^{-3} L 10^{2} $10^4 \ 10^5 \ 10^6 \ 10^7$ 10^{3} E/GeV ApJ Lett., 850:L35, 2017 arXiv:1802.04379 MeV neutrino wasn't observed by IceCube's noise rate and SK. ApJ Lett., 850:L35, 2017 arXiv:1802.04379 \circ anti- ν flux limit on the earth < 6.6x10⁷/cm² (luminosity at source ~<4x10⁵⁶ erg*)

ApJ Lett., 850:L35, 2017

GW170817 Neutrino limits (fluence per flavor: $\nu_x + \overline{\nu}_x$)

+500 sec time-window

0° promp

Auger

Fang & Metzger 30 days

 $10^8 \ 10^9 \ 10^{10} \ 10^{11}$

20

10¹²

10¹

10¹⁰

10⁵

10⁸

Fang & Metzger

3 days

SK limit, arXiv:1802.04379

V_x

100

total energy(MeV)

Auger

Kimura et al EE moderate

. Kimura et

*just my calculation

<u>BNS merger and thermal ν emission</u>



• assuming merger rate ~50/yr at ~200 Mpc

Ref.: Limits on ν from BBH merger



Time window for thermal ν search

Figure from ApJ, 846:114, 2017. This is likely to be underestimated (mentioned in arXiv:1710.05922).



- High emission period < 1 sec.
- TOF effect dominant for MeV neutrinos.

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

Calculation for ES:

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

This logic is from Borexino's GW paper (ApJ 850:21, 2017).

³ The *Planck* 2015 CMB temperature and polarization power spectra in combination with the baryon acoustic oscillations data gives a limit on the sum of neutrino masses $\sum m_{\nu} \leq 0.17$ eV at 95% C.L. [37]. Together with the measured oscillation mass differences [38] it leads to a constraint on the maximum neutrino mass m_1 , m_2 , m_3 of 70 meV.

And also, if BG is high, O(0.1 sec)-burst is worth being searched.

KamLAND DATA Quality

Detector condition



Event selection (IBD)

- Veto muon & events 2-msec after the muon.
- 2-sec veto after showering muon
- Likelihood selection
- Prompt Energy (Ep): 0.9—100 MeV (E_{ν} 1.8—100 MeV).
- Delayed Energy (Ed):
 1.8—2.6 MeV || 4.4—5.6 MeV
- Time correlation (dT): < 1000 μ s.
- Space correlation (dR): < 200 cm.

Overall detection eff. ~98%

←Different from usual analysis*.

*PRD 88 (2013) 033001.

BG rate for IBD search

Event selection

- Run014495—014546
- 2017/8/1—2017/8/30 (w/o 8/17): 24.4 livedays
- Rp, Rd < 6.0 m

Event rate:

120 evts/24day ~ 5.7e-5 evts/sec

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



Event selection (ES)

- Veto muon & events 2-msec after the muon.
- Visible Energy: 0.5—100 MeV (E_v: 0.67—100 MeV)
- Veto DC tagged events.

 Anti-neutrino candidates.
 Rn daughters.
- Veto badly reconstructed events.

Overall detection eff. ~99%

BG rate for ES search



EnergyKat (MeV)

BG rate for ES search



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

Event selection

2017/8/1-2017/8/30 (w/o 8/17): 24.4 livedays

Fiducial volume decision (ES)

Figure of merits relative to 600-cm-radius analysis: FOM =



 $(R/600 {\rm cm})^3$

Unblind

IBD search



ES search R<600cm, higher energy



No events above 3.5 MeV in +/-500 sec window. Consistent with expectation: 0.7.

ES search R<500 cm, lower energy



- E_{th} 1-MeV analysis
 - BG rate: 0.025/sec
- BG CONSistent • 10-sec expected: 0.25 evt.
 - N_{obs}: 1 evt.
 - Probability(N_{obs}>0): 22%
- E_{th} 0.5-MeV analysis
 - BG rate: 0.045/sec
 - 20-sec expected: 0.89 evt.
 - Observed: 1 evt.
 - Probability(N_{obs}>0): 59%

About the event

Occurred at Thu Aug 17 12:41:05.449 2017 UTC 1.02 sec after GW (0.72 sec before GRB).

E _{vis}	= 1.4 MeV	_
Х	= -137 cm	
У	= -81 cm	
Z	= 7 cm	
r	= 159 cm	

Relatively inside vertex.



1.4 MeV: ¹¹C dominant



ES search R < 450 cm, lower energy +/- 500 sec



- E_{th} 1-MeV analysis
- BG CONSISTENT • BG rate: 0.0056/sec
 - 1000-sec expected: 5.6 evt.
 - N_{obs}: 9 evt.
- E_{th} 0.5-MeV analysis
 - BG rate: 0.018/sec
 - 1000-sec expected: 19 evt.
 - Observed: 21 evt.

Fluence Upper Limit

monochromatic energy was assumed.

Time window comparison

v fluence UL on the Earth (90% CL)



Limits on all flavors (narrow window)

v fluence UL on the Earth (90% CL)





- MeV-neutrinos from BNS merger: GW170817 was searched with KamLAND.
- Time window for the search was modified for thermal ν .
- No IBD was found within +/-500 sec from t_{GW} .
- I ES candidate was found after 1 sec from GW.
 BG consistent with (500-cm-radius, 10-s-window, 1-MeV-E_{th}) analysis.
- KamLAND's sensitivity is <1/10⁶ of expected ν fluence.