Search for neutrino signal associated with Gravitational Wave from Binary Neutron-Star merger

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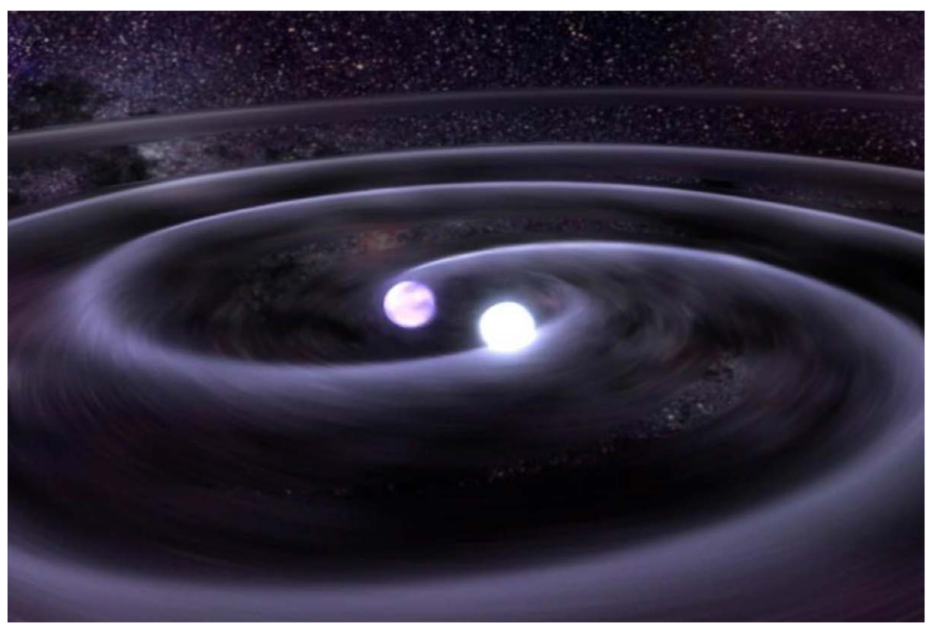
Binary Neutron-Star Merger

- **Unlike Black-Hole Merger, Binary Neutron-Star Merger can not only give Gravitational Wave but also enable electromagnetic channels, such as optical light, gamma ray, ultraviolet ray, infrared ray, etc.**
- **Neutrino detection will contribute to the multi-messenger observation and lead us to study the unknown equations of state for the supranuclear-density matter.**



How do neutrinos be emitted from BNS merger?

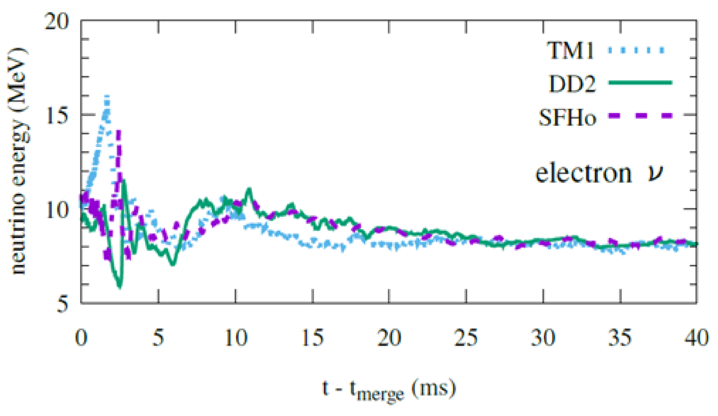
- **Currently little has been known about the realistic spectrum of neutrinos from BNS merger. However, it has been suggested that the spectrum can be approximated by pinched Fermi-Dirac distribution for the case of supernova explosions[1].**
- **The mechanism of neutrino emission from BNS merger can be considered as :**
  1. **e^+/e^- pairs produced from thermal photons as the matter temperature getting high.**
  2. **$\nu_e/\bar{\nu}_e$ emitted from e^+/e^- capture on nucleons. ($\bar{\nu}_e$ richness)**

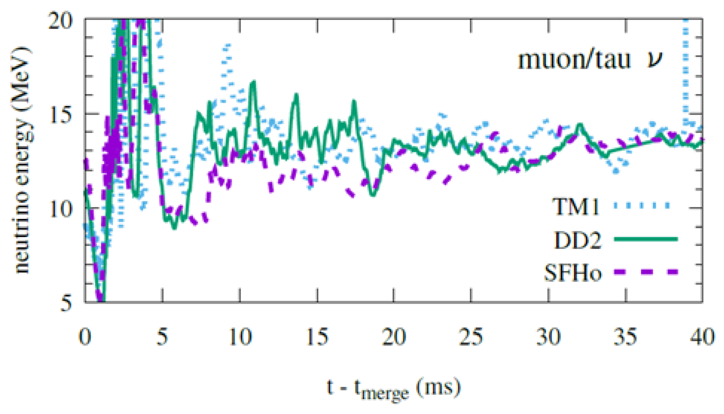
$$e^- + p \to \nu_e + n$$
$$e^+ + n \to \bar{\nu}_e + p$$

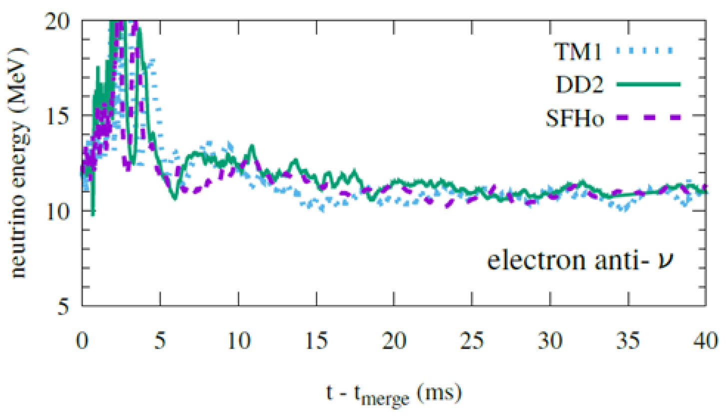
  3. **All neutrino types produced from e^+/e^- annihillation.**

$$e^+ + e^- \to \nu_x + \bar{\nu}_x$$

The expected neutrino energy after BNS merger[2]



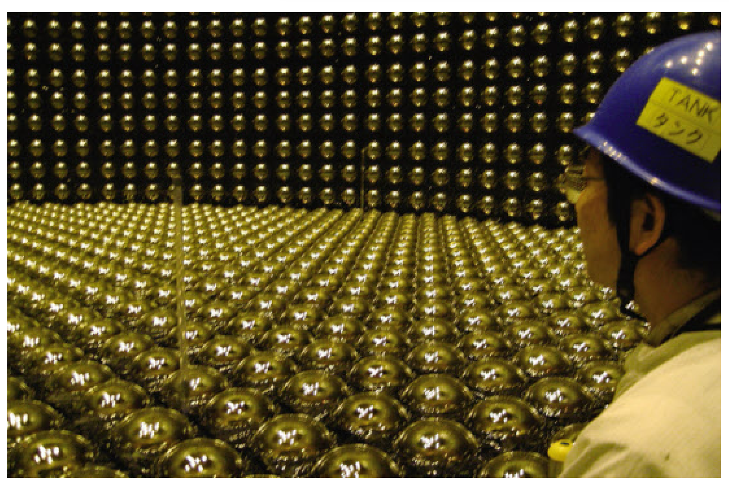




- **Typical energy of ν is 10~30MeV**
- **ν emission has a rise time of ~10ms**
- **Peak luminosity of $\bar{\nu}_e$ reaches $1\sim3\times10^{53}erg\cdot s^{-1}$**

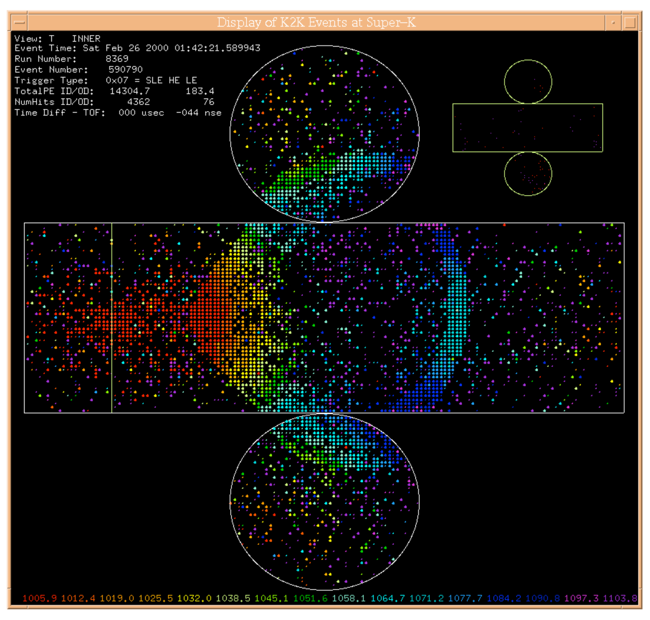
[1] S.Richers et al., The Astrophysical Journal, 813, 38 (2015)
[2] K.Kyutoku and K.Kashiyama, Physical Review D, 97, 103001 (2018)

Super-Kamiokande Detector



- **Built 1000m underground**
- **Water Cherenkov detector with best sensitivity to MeV neutrino**
- **50kton ultra pure water and 22.5kton fiducial volume**
- **~11000 PMTs in inner detector**

SK phase :
SK-I : 1996~2001
SK-II : 2002~2005
SK-III : 2006~2008
SK-IV : 2008~2018
SK-Gd : Coming soon !



GW170817

- **Detected by LIGO and Virgo on August 17th 2017 at 12:41:04 UTC**
- **The first evident signal of a gravitational wave from the BNS merger**
- **Total system mass of 2.74$M_\odot$ and a luminosity distance of 40Mpc**
- **The discovery of GW170817 marked the starting point of gravitational wave astronomy with BNS mergers**
- **Detected neutrinos in Water Cherenkov detector is approximately expected as[1] :**

$$N_\nu \approx 1.0\times10^{-3}\times f_E f_{SE} f_{OSC}\times\left(\frac{M_T}{1Mt}\right)\left(\frac{E_{\Delta T}}{3\times10^{52}erg}\right)\left(\frac{\langle E\rangle}{10MeV}\right)\left(\frac{D}{100Mpc}\right)^{-2}$$

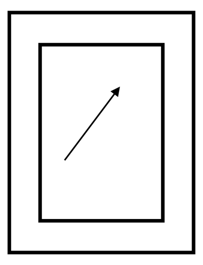
f_E: fraction factor of energy range, ~0.77 when $\langle E\rangle$=10MeV in 10~50MeV
f_{SE}: detection efficiency **f_{OSC}: factor of neutrino oscillation effect**
M_T: detector volume **D: distance to the source**

Neutrino signal search for GW170817 in Super-K

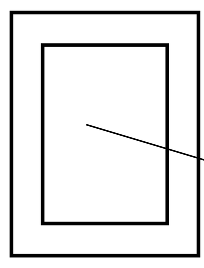
- **Two kinds of time window are used for search : ±500s and following 14-day.**
- **Five kinds of data reduction method are used for different energy ranges.**
- **LINAC(electron beam) calibration was performed in August 2017, but physics data taking was kept at the timing of GW170817. Due to so much low energy noises from beam work or hardware electronics in following days, 14-day search in 4~16MeV was not considered.**

Event associated with GW170817 in Super-K

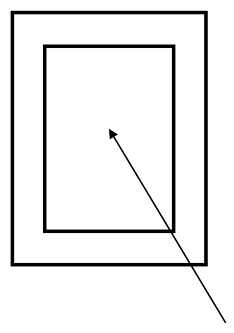
Data	Energy Range	Event in ±500s	Event in 14-day	Expected BG in 14-day
Solar ν search	4~16MeV	0		
Supernova Relic ν search	16~100MeV	0	2	1.53
Fully-Contained	100MeV~10GeV	0	76	91.44
Partially-Contained	100MeV~10GeV	0	8	7.35
Up-going μ	1.6GeV~100PeV	0	13	16.05



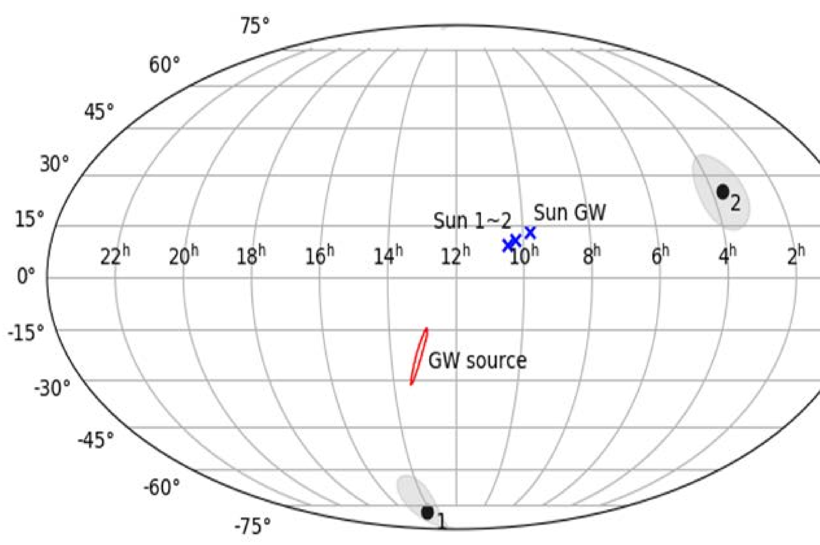
Partially-Contained



Fully-Contained



Up-going μ

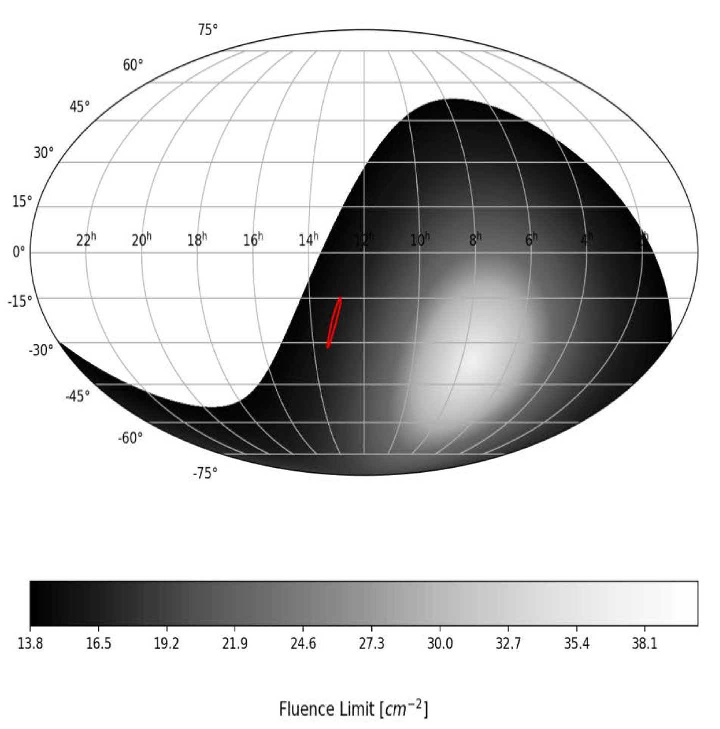


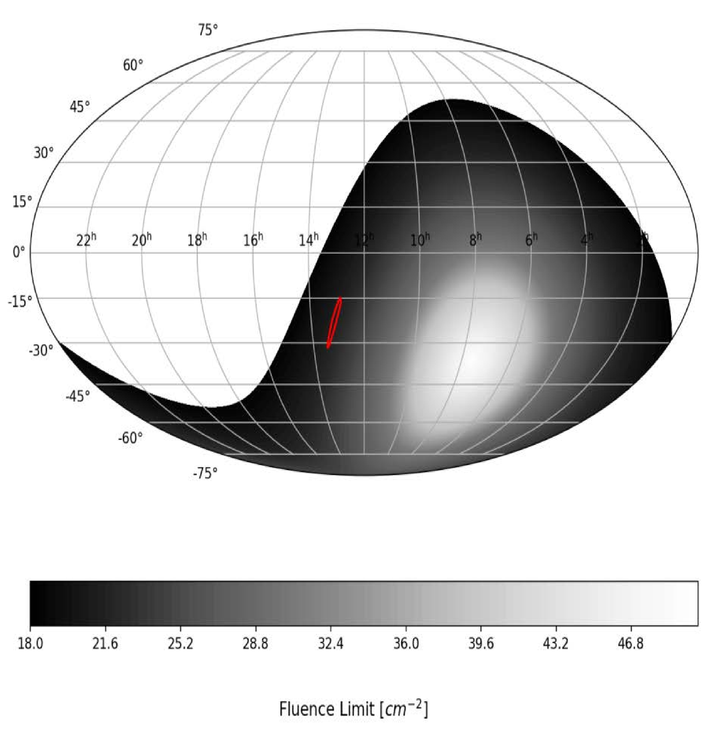
- **Events in 14-day of 16~100MeV**

	Reconstructed E	UTC Time	Direction
1	22.5MeV	August 23th 7am	Figure Left
2	40.9MeV	August 28th 10am	

- **Red : LIGO public data with 90% C.L.**
- **Shadow : angle resolution range**

Zenith-dependent Fluence Limit result for Up-going μ in ±500s window[2]





[1] K.Kyutoku and K.Kashiyama, Physical Review D, 97, 103001 (2018)
[2] K.Abe et al., The Astrophysical Journal Letters, Vol. 857, No. 1, L4 (2018)

Summary & Future Plan

- Neutrino signal search associated with GW170817 was done in Super-K, no signal found, and fluence limit has been derived.
- SK-Gd will increase $\bar{\nu}_e$ sensitivity by 2 orders in the range of a few tens MeV.
- Hyper-K, a Water Cherenkov detector with 260kton volume in the plan, can bring a larger target for neutrino signal from BNS mergers.

XVIII International Workshop on Neutrino Telescopes, 18-22 March, 2019, Venice, Italy