Monitoring low energy astrophysical neutrinos in JUNO

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ABSTRACT

With its unprecedented sensitivity to MeV-scale neutrinos, the Jiangmen Underground Neutrino Observatory (JUNO) will play an essential role in the emerging field of multi-messenger astronomy, especially in capturing next galactic core-collapse supernova (CCSN). Two real-time monitoring systems have been designed to detect the forecasted burst of neutrinos from a CCSN in JUNO. Here we present a dedicated CCSN monitoring system and its sensitivity to supernova neutrinos including a variety of supernova models. Assuming a yearly false alert rate, JUNO expects to be sensitive to neutrinos from a 30 $M_\odot$ progenitor up to 370 (360) kiloparsecs, with normal (inverted) mass ordering. The possibility to boost the CCSN sensitivity will be presented, including the one to low energy all-flavours neutrino events, made accessible with JUNO's Multi-messenger trigger system, which aims to reduce energy thresholds to approximately 20 keV.

JUNO Detector

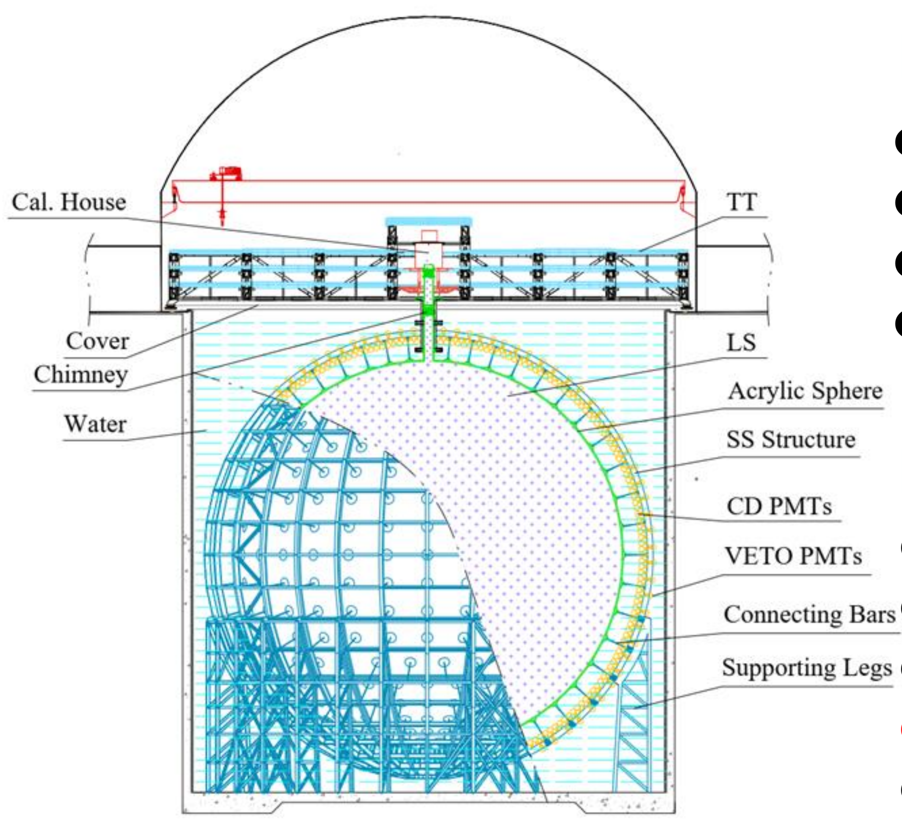


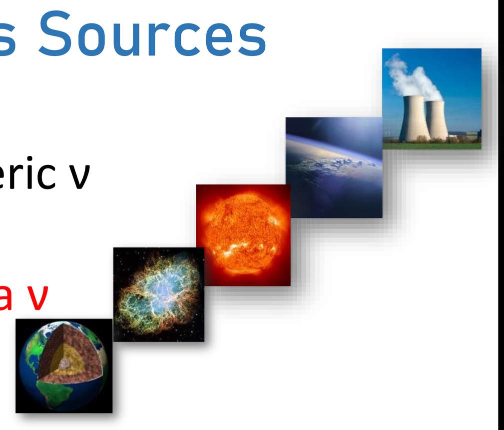
Figure 1: JUNO schematic [1]

Detector

- 20 kiloton liquid scintillator(LS)
- 35 kiloton ultrapure water
- 17,612 20"+ 25,600 3" PMTs
- < 3% energy resolution @1MeV

Neutrinos Sources

- Reactor ν
- Atmospheric ν
- Solar ν
- Supernova ν
- Geo- ν



CCSN Real Time Monitor System

The real-time monitoring system aims to provide early alerts and record CCSN data comprehensively. To ensure redundancy, the design includes both a **prompt monitor** and an **online monitor**. If an alert is found, it will be sent to the internal collaboration and the astronomical community [2].

Online Monitor:

- Implemented on data acquisition(DAQ)
- Based reconstructed events
- Accurate alert efficiency.
- SN & pre- SN

Prompt Monitor:

- Implemented on electronics board.
- Based on trigger.
- Fast alert time
- SN

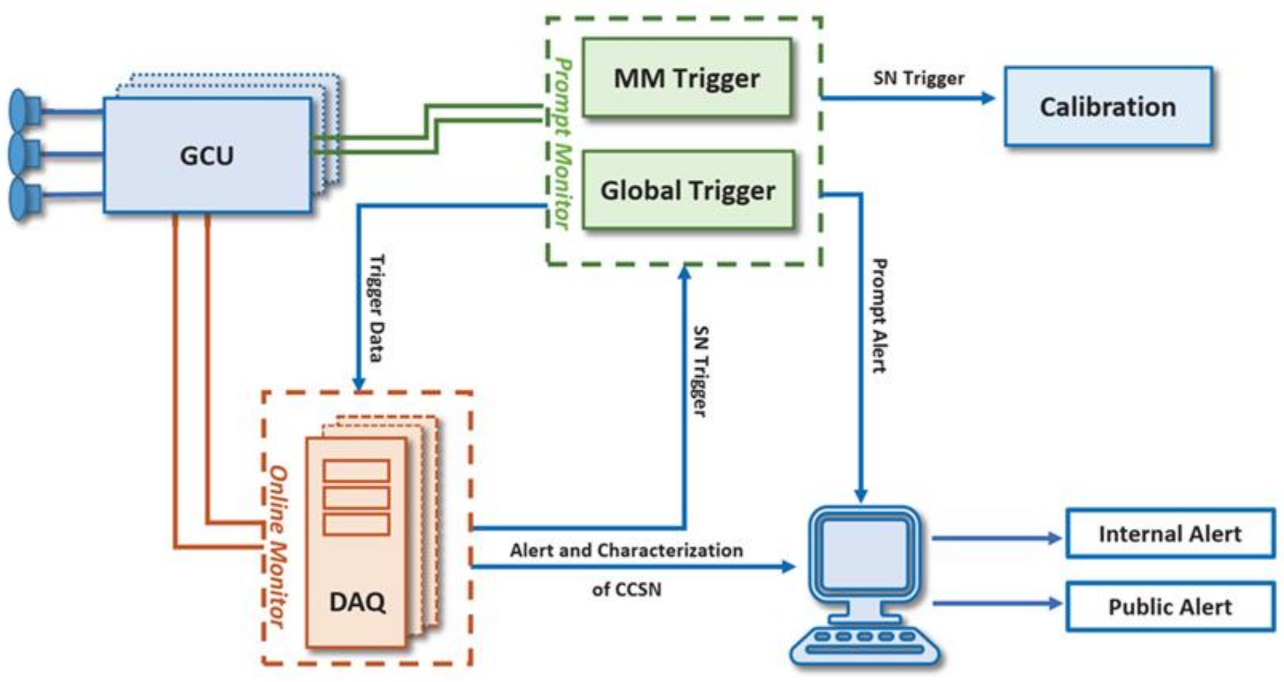


Figure 3: The schematic overview of JUNO's real time monitor system.

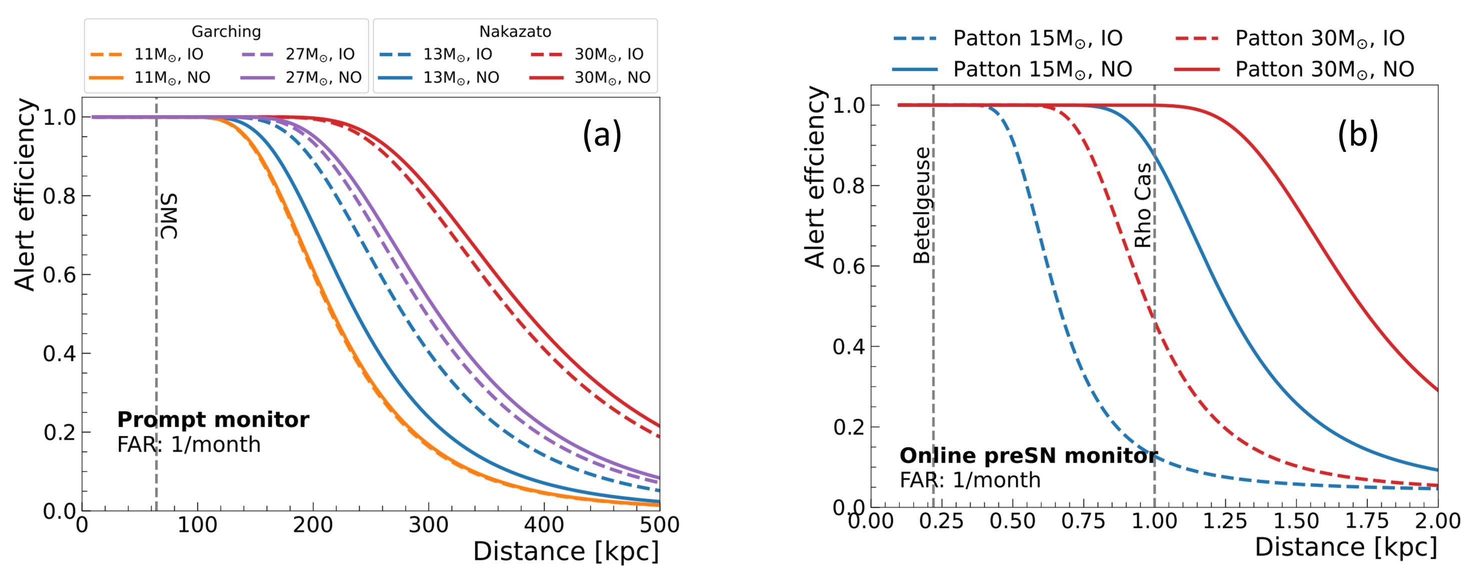


Figure 4: Sensitivity of prompt monitor (a) and online pre SN monitor (b) for different models [2].

SN monitor:

- ➢100% alert efficiency for Small Magellanic Cloud (SMC).
- ➢Alert Time: 15~30 ms.

Pre-SN monitor:

- ➢100% alert efficiency for Betelgeuse.
- ➢Alert Time: 3~120 hours before SN explosion.

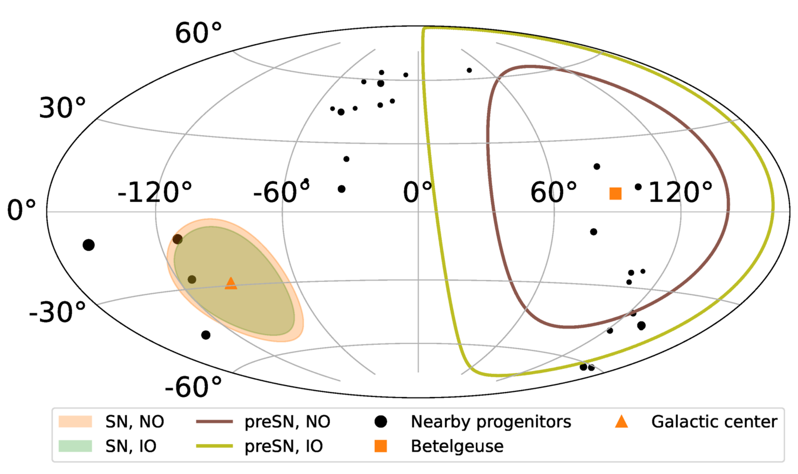


Figure 5: Sky-map of pointing resolution for pre-SN and SN cases [2].

Pointing Performance

- Based on anisotropy of the IBD events.
- Betelgeuse-like star pre-SN pointing: 56° (81°), NO (IO) for 15 $M_\odot$ Patton.
- Typical CCSN at 10 kpc SN pointing: 26° (23°), NO(IO) for 13 $M_\odot$ Nakazato.

Core-Collapse Supernova(CCSN) Neutrinos

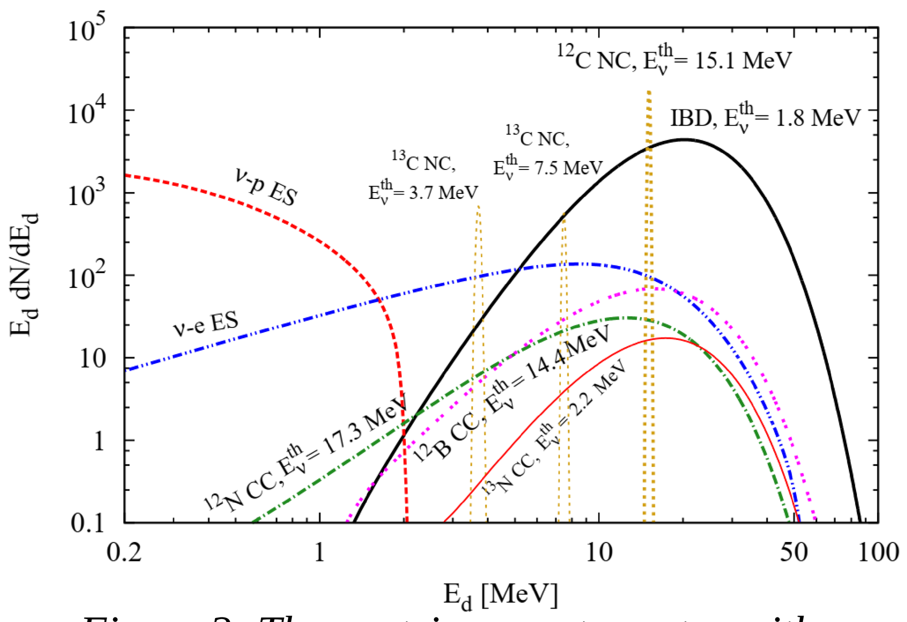


Figure 2: The neutrino event spectra with respect to the visible energy in JUNO for a CCSN at 10kpc [1].

Inverse Beta Decay (IBD):

- Anti-electron neutrino.
- Primarily high energy (O(10MeV)).
- Minimal backgrounds.

Proton elastic scattering (pES):

- All neutrino flavours.
- Lower energies. If 20 keV cut, event number ~ 6000.
- ν_e expected to arrive earlier than $\bar{\nu}_e$.

	Process		Num. Events (0.2 MeV Cut)
IBD	$\bar{\nu}_e + p \to e^+ + n$		~5000
pES	$\nu + p \to \nu + p$	$(\overset{(-)}{\nu}_{e,\mu,\tau})$	~2000
eES	$\nu + e \to \nu + e$	$(\overset{(-)}{\nu}_{e,\mu,\tau})$	~400
CC	$\overset{(-)}{\nu}_e + ^{12}C \to e^{-(+)} + ^{12}N(^{12}B)$		~200
NC	$\nu + ^{12}C \to \nu + ^{12}C^* \to \gamma(15.11\text{MeV})$	$(\overset{(-)}{\nu}_{e,\mu,\tau})$	~300

Table 1: Expected Neutrino Event Number @ JUNO (CCSN @10kpc)

Multi-Messenger(MM) Trigger System

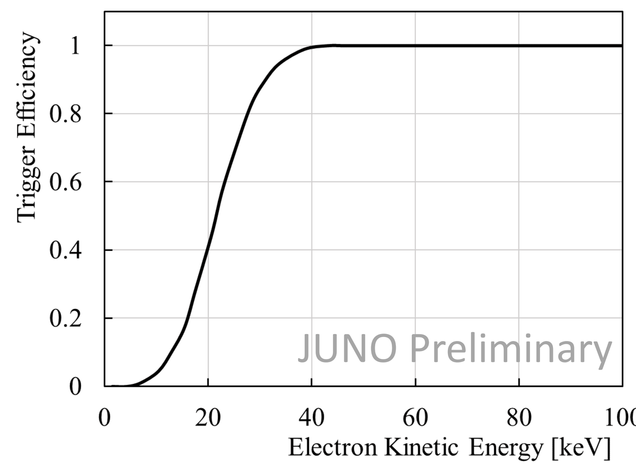


Figure 6 : MM trigger efficiency [3]

- A multi-messenger transient machine.
- Aims to reach ~20 keV energy threshold.
- Likelihood algorithm on processing unit (PU) can remove 99.97% dark noise.
- Challenge from high rates of ^{14}C β-decay.

Figure 7 : Multi-messenger trigger processing unit – TeraBox 1100L

2D Bayesian Block Algorithm(BBA)

A Bayesian Block Algorithm[4] on PU searches for bursts in triggered event time series. New implementation using a 2D time-energy BBA search aims to extend JUNO's alert sensitivity.

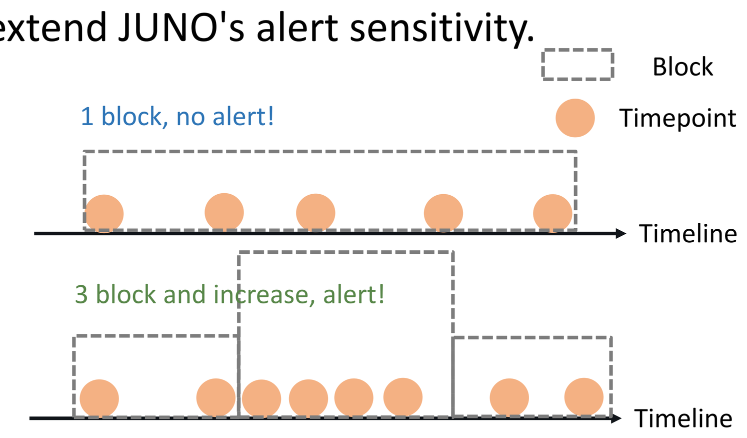


Figure 8: BBA will generate more than one block when time series are clustered.

If a timepoint's energy matches the background, its size is 1. If it matches a supernova neutrino, its size is greater than 1.

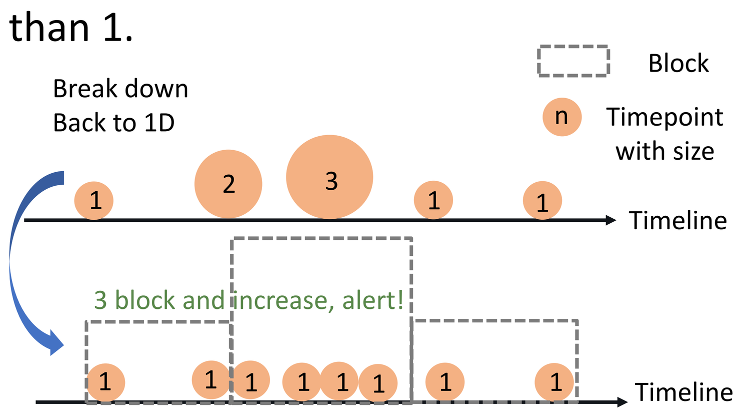


Figure 9: 2D BBA adjust the time point size with another dimension like energy.

Other Astrophysical Potential

- Solar neutrinos from the pp chain, which require a very low energy threshold. Need to precisely measure the ^{14}C spectrum and pile-up events [5].
- Neutrino magnetic moment: can be tested by measuring electron elastic scattering (eES) cross section precisely [6].
- Binary neutron star (BNS) merger neutrinos. When BNS merge, neutrino emission luminosity can also achieve about 10^{53}erg/s [7], similar to that of a supernova.

Reference

[1] Angel Abusleme et al. "JUNO physics and detector", *Prog. Part. Nucl. Phys. 123 (2022) 103927.*
[2] Angel Abusleme et al. "Real-time monitoring for the next core-collapse supernova in JUNO". *JCAP01(2024)057.*
[3] Iwan Morton-Blake et al. "Extending JUNO's Astrophysical Reach with a Low-Energy Multi-Messenger Trigger System". *Proceedings of 38th International Cosmic Ray Conference — PoS(ICRC2023).*
[4] Brian Pollack et al. "Bayesian Block Histogramming for High Energy Physics". *arXiv: 1708.00810.*
[5] Kumaran, S, G et al. "Borexino Results on Neutrinos from the Sun and Earth". *Universe 2021, 7, 231.*
[6] Ziping Ye et al. "Unambiguously Resolving the Potential Neutrino Magnetic Moment Signal at Large Liquid Scintillator Detectors". *Chin. Phys. Lett. 2021, 38 (11): 111401.*
[7] Marco Cusinato et al. "Neutrino emission from binary neutron star mergers: characterizing light curves and mean energies". *Eur. Phys. J. A 58, 99 (2022).*