Real-time Monitoring of Astrophysical Neutrinos with the Multi-messenger Trigger of JUNO

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Abstract

A new era of multi-messenger astronomy has arrived with the detection of gravitational waves and high-energy astrophysical neutrinos. The successful coordination of near real-time follow-up campaigns with multi-messenger instruments of those events have largely extended our understanding of the most violent phenomena in the Universe. With its unprecedented sensitivity to MeV scale neutrinos, the Jiangmen Underground Neutrino Observatory (JUNO) will contribute significantly to this exciting new field. We will present a model-independent real-time monitoring system on JUNO, and its sensitivities to transient phenomena such as core-collapse supernova burst and pre-burst neutrino signals. Preliminary study shows that, with such algorithm implemented on the multi-messenger trigger system of JUNO, it is able to make a 5-σ detection of neutrinos from core collapse supernovae at a distance of 100 kpc. If the core collapse supernova is to be happen within 1 kpc, the pre-supernova neutrinos can be detected at 3-σ significance, and at least 5 hours before the core collapse.

Real-time Monitoring of Astrophysical Neutrinos

Multi-messenger (MM) Trigger of JUNO

- Two trigger systems in JUNO: global trigger & MM trigger ;
- Global trigger threshold ~ 200 keV ;
- MM trigger threshold ~ 20 keV ; low threshold → broadband observation window .

For more details, please refer to Poster #129: Multi-messenger and Low-threshold Trigger System of JUNO .

Event Selection

- Select IBD : (1) prompt signal energy $E_{pr} \geq 1$ MeV ; (2) delayed signal energy $E_{de} \approx 2.2$ MeV ; (3) delayed–prompt time difference $\Delta T < 1$ ms ; (4) delayed-prompt spatial distance $R_{pr-de} < 1.5$ m .
- Select vpES : pulse shape discrimination (PSD) between proton recoil signals and beta/gamma backgrounds .
- Select veES : (1) energy cut $E_e \geq 10$ MeV ; (2) PSD between e^- and e^+ .

Particles	Fast τ_1 / fraction f_1	Slow τ_2 / fraction f_2	Slower τ_3 / fraction f_3
γ , e^- , e^+	4.9 ns / 79.9 %	20.6 ns / 17.1 %	190.0 ns / 3.0 %
p , n	1.0 ns / 65.0 %	34.0 ns / 23.1 %	220.0 ns / 11.9 %
α	1.0 ns / 65.0 %	35.0 ns / 22.8 %	220.0 ns / 12.2 %

Table 1: The fractions of scintillation light in the three components (fast , slow and slower) for different types of particles, which is the basis of PSD [1].

Monitor Neutrino Signal Rate (Bayesian blocks algorithm)

- Bayesian blocks algorithm (BBA) [2] : real-time monitoring of neutrino signal rate ;
- Model-independent, time-scale-independent (i.e. pre-supernova ~ days, core collapse supernova ~ 10 s, type-Ia supernova ~ 1 s, etc.)
- If BBA discovers significant change of event rate, forms an alert .
- On an alert, JUNO will enter a special triggerless DAQ mode that saves the T/Q of all hits .

JUNO will join in the global network of multi-messenger observations, both provide alerts and respond to the alerts from the network.

Backgrounds in JUNO

Backgrounds for Monitoring Astrophysical Neutrinos

- ^{14}C β-decay backgrounds ~ 40 kHz (assume ^{14}C abundance of 10^{-17}) , can be reduced by PSD to ~ 0.5 kHz (above 100 keV).
- Cosmogenic neutrons induced by muon spallation, can be reduced by removing the data within 1 ms after muons, because most of the neutrons are captured within 1 ms of the muon spallation event.

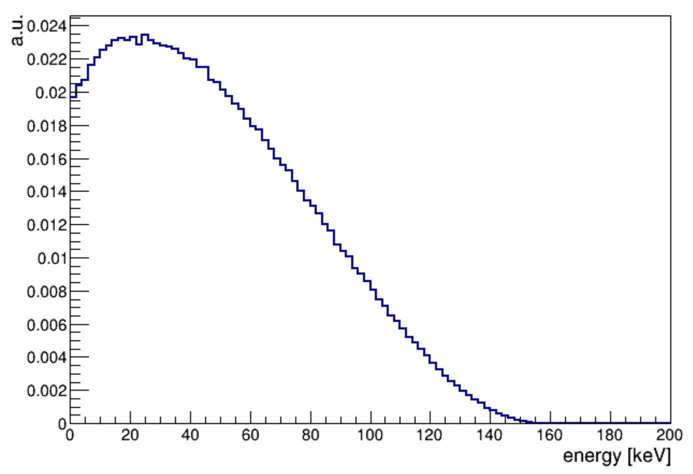


Figure 7: Spectrum of ^{14}C β-decay, with an endpoint energy of 156 keV.

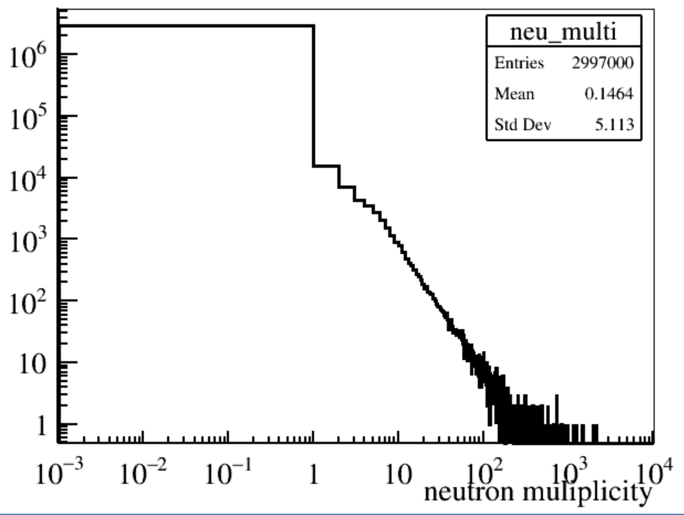


Figure 8: The number spectrum of cosmogenic neutrons produced by muon spallation.

JUNO Detector

JUNO Detector

- 20 kiloton liquid scintillator detector
- 18,000 20-inch + 25,000 3-inch PMTs
- Energy resolution ~ 3% / $\sqrt{E(\mathrm{MeV})}$
- Light yield ~ 1200 PE / MeV

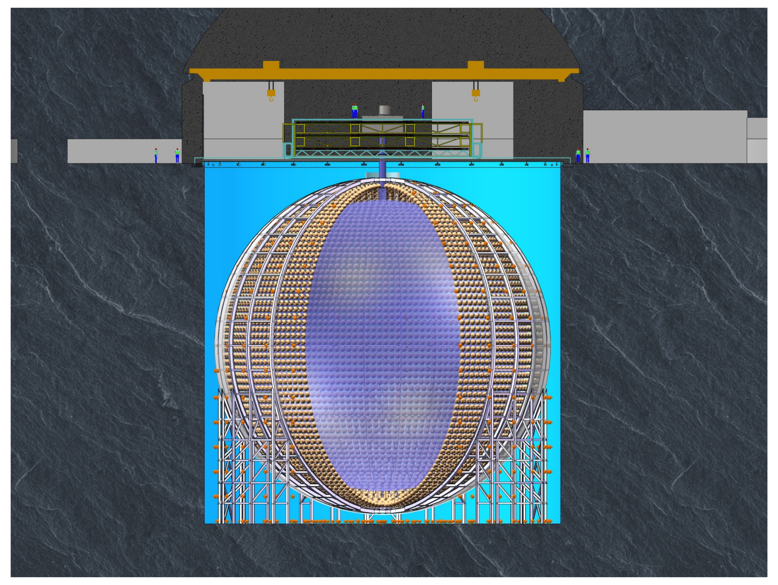


Figure 1: JUNO detector: the central detector is an acrylic sphere filled with 20 kton liquid scintillator; the outer water pool is the muon veto; another muon tracker is placed on top of the water pool [1].

Detection Channels for Neutrinos

- Inverse beta decay (IBD)
  $\bar{\nu}_e + p \rightarrow e^+ + n$
- ν-proton elastic scattering (νpES)
  $\nu_x + p \longrightarrow \nu_x + p$
- ν-electron elastic scattering (νeES)
  $\nu_x + e^- \longrightarrow \nu_x + e^-$
- ν- ^{12}C interactions (several interactions, for ν_e , $\bar{\nu}_e$, or all types)

Core-collapse Supernova Burst & Pre-burst Neutrinos

Pre-supernova Neutrinos

- Monitor IBD event rate induced by pre-supernova neutrinos; early warning for supernova [3] [4].

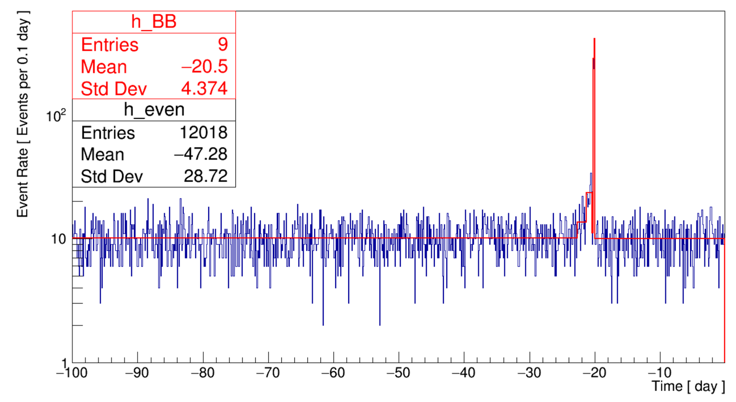


Figure 2: Time profile of pre-supernova neutrino IBD rate (for a 20 $M_\odot$ star at 0.2 kpc), with other IBD backgrounds in JUNO. Bayesian blocks algorithm will find the significant change of the event rate.

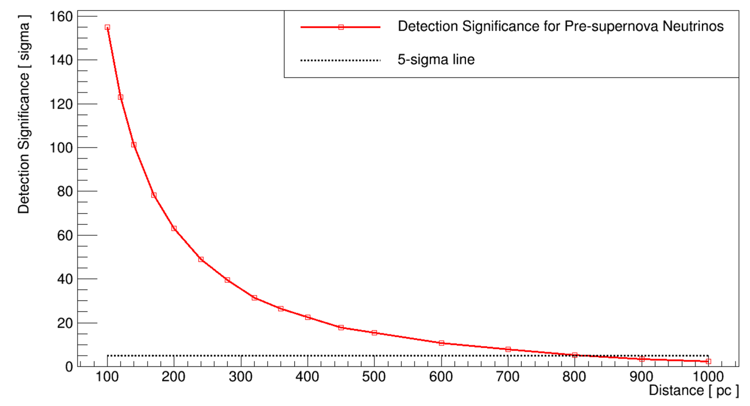


Figure 3: Detection significance of pre-supernova neutrinos. About 3-σ detection at 1 kpc .

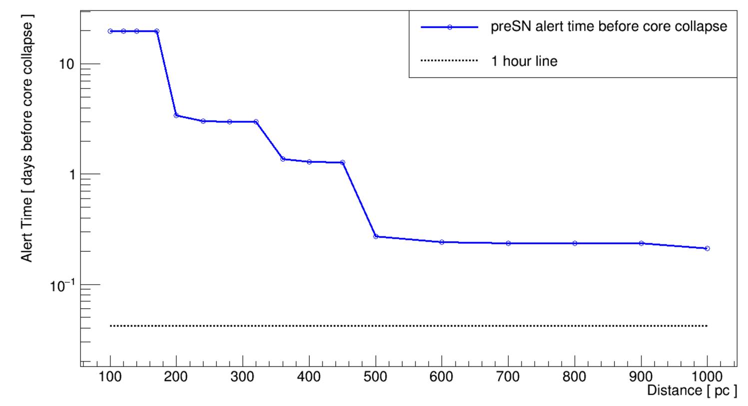


Figure 4: The amount of time between alert and core collapse. About 5 hours early warning for a pre-supernova at 1 kpc .

Core Collapse Supernova Neutrinos

- Neutrino-trapping & neutronization burst yet to be observed [5];
- Accretion phase – key to how supernova explode;
- Cooling phase: neutron star properties, new particles .

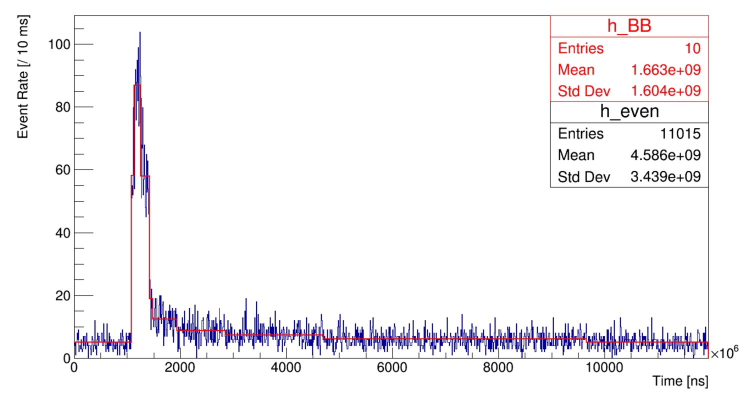


Figure 5: Time profile of supernova neutrino signals (for a 27 $M_\odot$ star at 20 kpc), with backgrounds (after event selection). Bayesian blocks algorithm will find the change of event rate and form an alert.

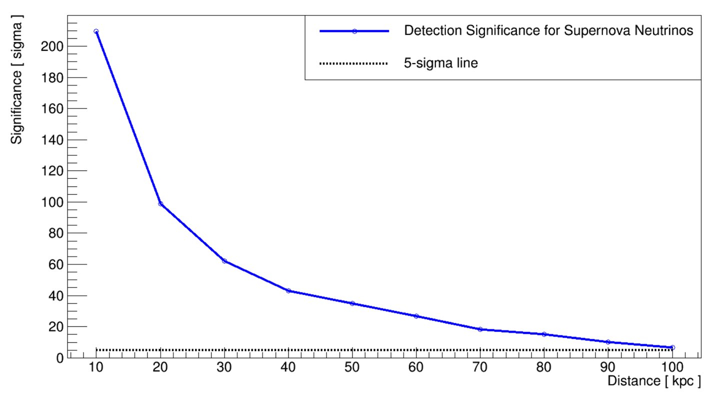
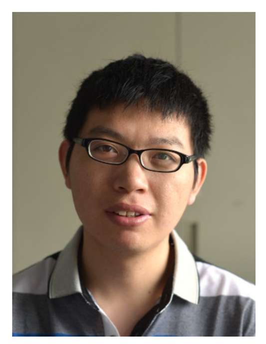


Figure 6: Detection significance of supernova neutrinos. About 5-σ detection at 100 kpc (for comparison, Milky Way radius is ~ 15 kpc, SN1987A [6] in the Large Magellanic Cloud is at a distance of 50 kpc).

References

[1] JUNO collaboration, Journal of Physics G 43 (2016) 030401.
[2] J.D. Scargle, et al. The Astrophysical Journal (2013).
[3] G. Guo and Y.Z. Qian, Verhandlungen der Deutschen Physikalischen Gesellschaft, (2018).
[4] H. Li, Y. Li, L. Wen, S. Zhou, JCAP 05 (2020) 049.
[5] A. Mirizzi, I. Tamborra, H.T. Janka, et al. La Rivista del Nuovo Cimento, (2016).
[6] R. Schaeffer, Y. Declais, S. Jullian, Nature 330 (1987).



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