Prospects for Detecting the Diffuse Supernova Neutrino Background with JUNO

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The Jiangmen Underground Neutrino Observatory (JUNO) is located 650 meters underground in southern China. This poster presents detection potential for the diffuse supernova neutrino background (DSNB) at JUNO using the inverse-beta-decay (IBD) detection channel. With latest DSNB signal predictions, more realistic background evaluation and efficiency optimization of pulse shape discrimination (PSD), and additional triple coincidence cut, JUNO can reach the significance of 3σ for 3 years of data taking, and achieve better than 5σ after 10 years for a reference DSNB model. In the pessimistic scenario of non-observation, JUNO would strongly improve the limits and exclude a significant region of the model parameter space.

The JUNO experiment

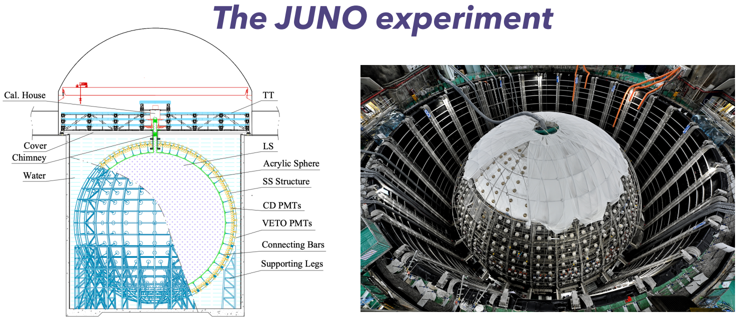


Fig. 1 JUNO detector. Left: schematic drawing, right: Installation photo of June 6th

- A multi-purpose observatory for determining the neutrino mass ordering, precisely measuring $\sin^2 2\theta_{12}, \Delta m^2_{21}, \Delta m^2_{31}$, studying the solar neutrinos, supernova neutrinos, diffuse supernova neutrino background, etc. [1]
- 20 kton liquid scintillator (LS); 3% @ 1 MeV unprecedented energy resolution; a muon rate of 0.004 Hz/m^2. [1, 2]

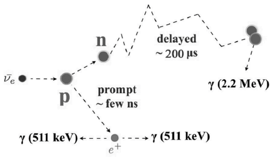
DSNB signal prediction

- Core-Collapse Supernova (CCSN) is the final stage of massive stellar with m > 8 $M_\odot$.
- **The vast number of neutrinos produced by all supernova explosions form the DSNB, which has not yet been detected.**
- **Detection via inverse beta decay (IBD)**

$$\frac{d\phi}{dE_\nu} = \int_0^{z_{\max}} R_{\rm SN}(z) \frac{dN(E'_\nu)}{dE'_\nu}(1+z)\left|\frac{cdt}{dz}\right| dz$$

$d N_\nu / d E_\nu$ is the neutrino spectrum of CCSN

R_{SF} is the formation rate of stellar



Ratio of black-hole-forming f_{BH}: 0 ~ 0.4; $R_{SN}(0)$: 0.5 ~ 2 10^{-4}yr-1Mpc^{-3}
$E_{\rm total}$, $\langle E_\nu \rangle$, $\langle E_\nu^2 \rangle$ of failed SNe: 8.6×10^{52}erg, 18.72 MeV, 470.76 MeV^2
$E_{\rm total}$, $\langle E_\nu \rangle$, $\langle E_\nu^2 \rangle$ of successful SNe: 5.0×10^{52}erg, 12~18 MeV, $1.25\langle E_\nu \rangle^2$

Background evaluation

- **Fast neutron (FN) background** is evaluated by the simulation of untagged muons in the surrounding rocks and water pool.
- **Atmospheric ν ^{12}C NC background** is evaluated by two neutrino generators GENIE and NuWro. An *in situ* measurement gives an NC background uncertainty of 35% for the first 3 years of data taking, and an uncertainty of 25% (15%) after three (nine) years. [4]
- **Other backgrounds** are negligible within the prompt energy range [12, 30] MeV.

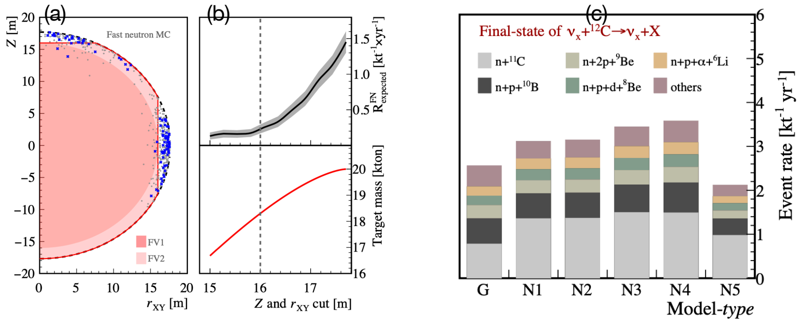
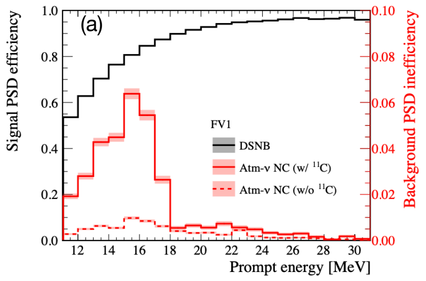
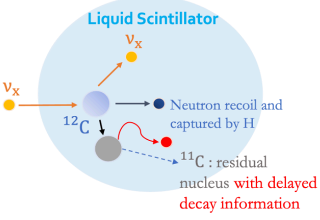


Fig.2 (a) Spatial vertex distributions of the simulated FN background. (b) The event rate of FN background in terms of the Z and r_{XY} cut for the prompt energy of [12, 30] MeV.(c) Event rates of the NC background for specific channels with different final-state nuclei in the prompt energy range from 12 to 30 MeV.

Background suppression

- **Muon veto:** suppresses the spallation neutron background.
- **Pulse shape discriminate (PSD):** suppresses the FN and NC background. The performances depend on vertex, particle-type and energy. [3, 5]
- **Triple coincidence (TC):** suppresses the NC background with ^{11}C. The inefficiency of **TC**-cut is 25.5% for NC background with ^{11}C in FV1.





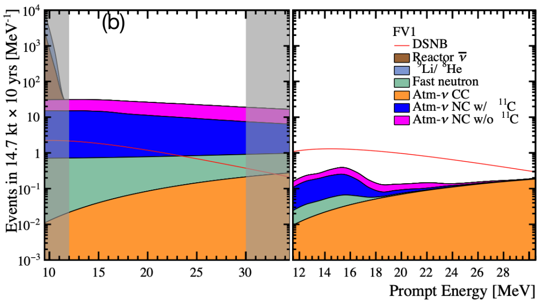


Fig.3 **(a)** PSD efficiencies as functions of the prompt energy with the BDT method. **(b)** The prompt energy spectra of the reference DSNB signal in FV1 before (left) and after (right) the background reduction techniques.

Sensitivity

In the condition of f_{BH}=0.27, $R_{SN}(0)$=10^{-4}yr-1Mpc^{-3}, $\langle E_\nu \rangle$=15 MeV, the event rates of the DSNB signal and total backgrounds is 19.2 and 5.4 per 183 kt · yr in [12, 30] MeV in FV1+FV2 after all cuts, respectively.

$$\chi^2(\langle E_\nu\rangle, f_{\rm BH}, R_{\rm SN}(0)) = \sum_i -2\log\left[P\left(n_i, \Phi s_i + \sum_j f_j b_{j,i}\right)\right] + \sum_j \frac{(f_j-1)^2}{\sigma_j^2}$$

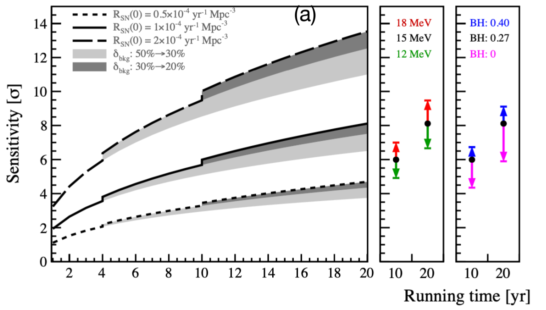
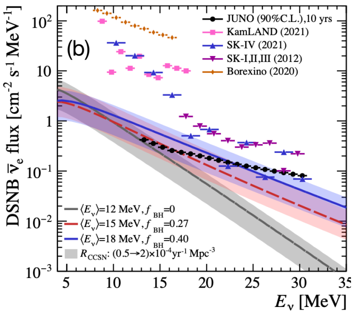


Fig. 4 **(a)** DSNB discovery potential (σ) at JUNO . $\sigma = \sqrt{|\chi^2_{\min}(\Phi=0) - \chi^2_{\min}(\Phi=1)|}$.**(b)** 90% confidence level upper limits on the DSNB fluxes for 18 equal neutrino energy bins from 12 to 30 MeV, derived using **bin by bin simply rate counting and Feldman-Cousins (FC) statistics.**



Conclusion

- For the reference DSNB model, JUNO can reach the significance of 3σ for around 3 years of data taking, and better than 5σ after 10 years. [2]
- Compared to KamLAND and SK, JUNO can improve the DSNB flux limits by 0.5 to 2 order of magnitude.[2]

References

[1] JUNO Collaboration, J. Phys. G 43 (2016) 030401.
[2] JUNO Collaboration, JCAP 10 (2022), 033.
[3] J. Cheng et.al. Phys.Rev.D 103 (2021) 5, 053001.
[4] J. Cheng et.al. Phys. Rev. D 103 (2021) no.5, 053002
[5] G. Huang et al. Nucl. Sci. Tech. 34 (2023) no.6, 83

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