Prospects for Detecting the Diffuse Supernova Neutrino Background with JUNO

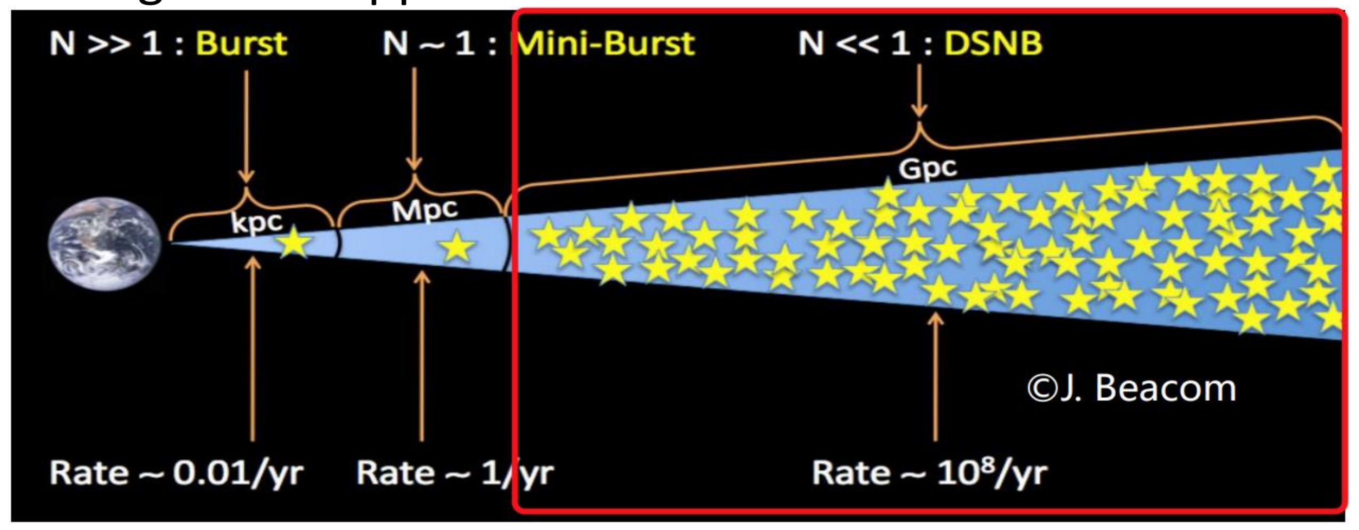
Presented by **Yiyu Zhang** on behalf of JUNO Collaboration
Institute of High Energy Physics, CAS, China

Based on arXiv: 2205.08830

ICHEP 2022 BOLOGNA

I. Diffuse supernova neutrino background

- Neutrino source: all past core-collapse supernovae
- Detection: IBD in LS and water detector
- Key factors for DSNB:
  - Detector size (JUNO, SuperK-Gd, …)
  - Background suppression



DSNB flux:

cosmological SN rate

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

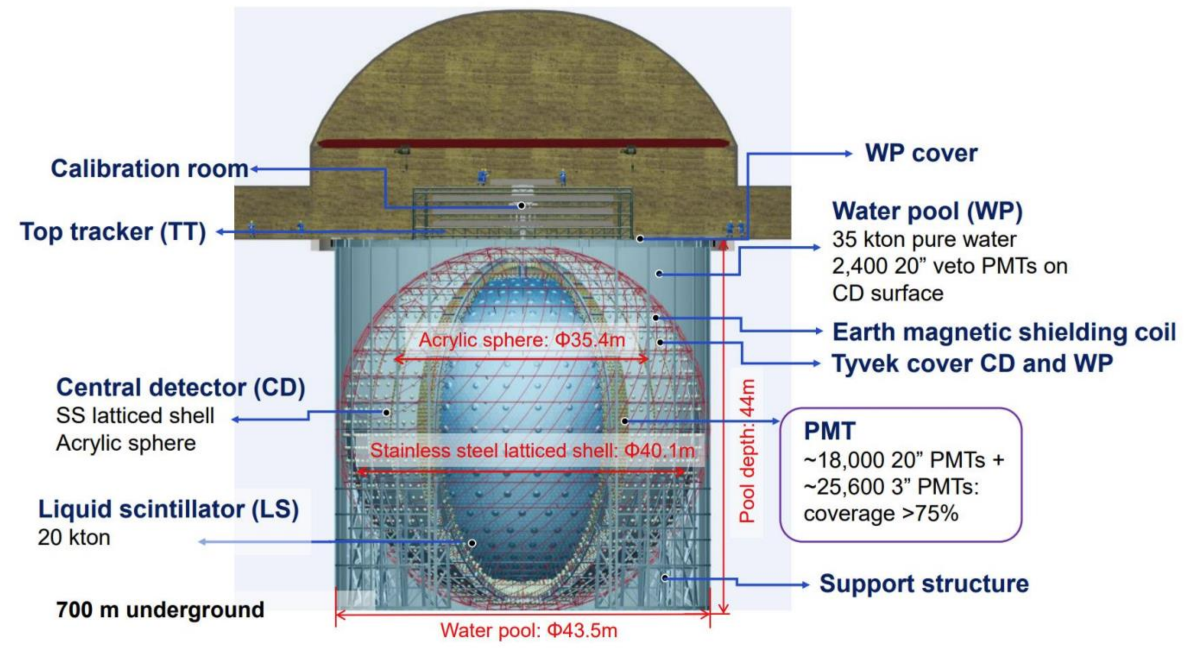
the nominal model: $\langle E_\nu \rangle \sim 15$ MeV, $f_{BH} \sim 0.27$, $R_{SN}(0) \sim 1\times10^{-4}\,\mathrm{yr^{-1}Mpc^{-3}}$

fraction of failed black-hole-forming SNe

$$\frac{dN(E_\nu)}{dE_\nu} = (1-f_{BH})\frac{dN_{SN}(E_\nu)}{dE_\nu} + f_{BH}\frac{dN_{BH}(E_\nu)}{dE_\nu}$$

SN spectrum: depends on average energy of SN neutrinos $\langle E_\nu \rangle$

II. JUNO detector



- With 20 kt of liquid scintillator, JUNO has the potential for a DSNB measurement

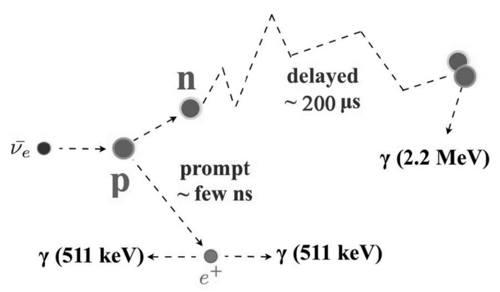
III. Signal prediction

DSNB primary detection via **inverse beta decay (IBD)**

$\bar{\nu}_e + p \rightarrow e^+ + n$

Prompt Delayed

- JUNO: neutron captured in H



DSNB signal spectrum in detector

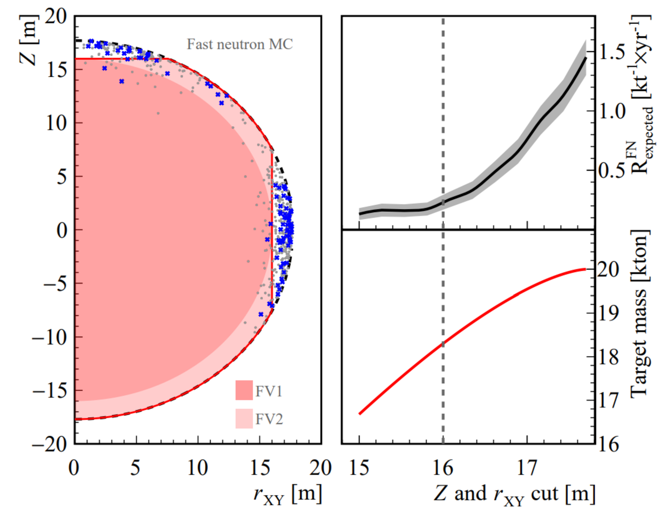
Measured energy → $\frac{dS(E_{\text{prompt}})}{dE_{\text{prompt}}} = N_p \times \sigma(E_\nu) \times J(E_\nu) \times \frac{d\phi}{dE}(E_\nu)$ → DSNB flux

Detector capability

IV. Background evaluation

- **Neutral-current (NC)** interactions of atm. neutrino with ^{12}C in LS is the most significant background source in the DSNB study
  - Methods of model prediction from **Phys.Rev.D103 (2021) 5, 053001**
  - Two widely-used neutrino generators GENIE and NuWro are used to model the interactions
  - Add deexcitation and delayed decay processes of the residual nuclei
- **Fast neutron**: generated by muon spallation in the rock surrounding the detector; higher at the surface of the CD.

  Two fiducial volumes: FV1 and FV2
  - FV1 (inner region)
  - FV2 (outer region)
  - Background suppression strategies are different in FV1 and FV2

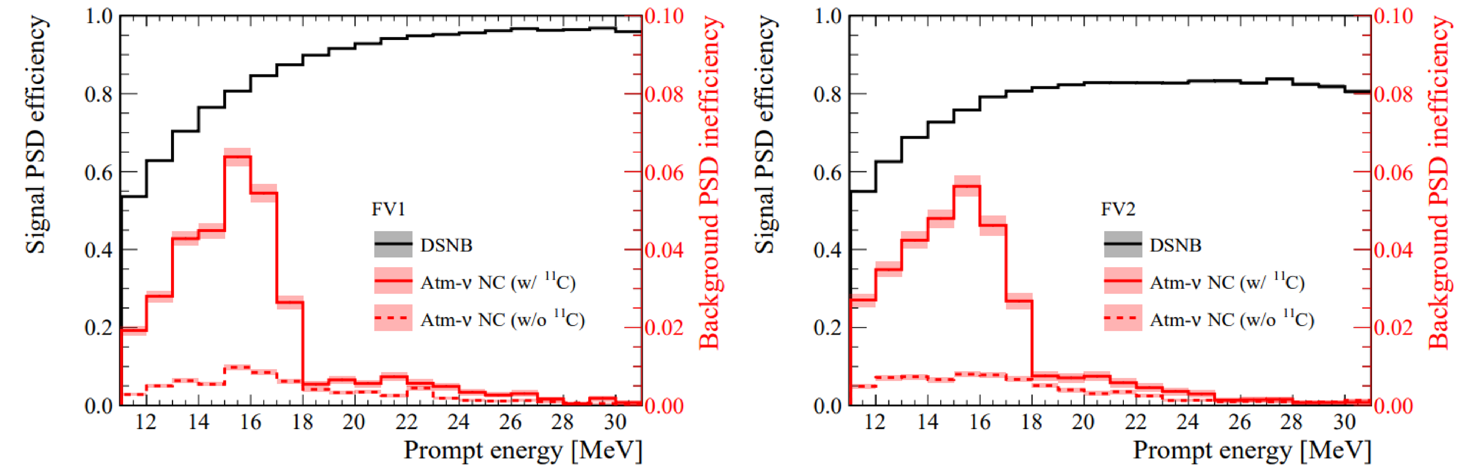


- Other backgrounds:

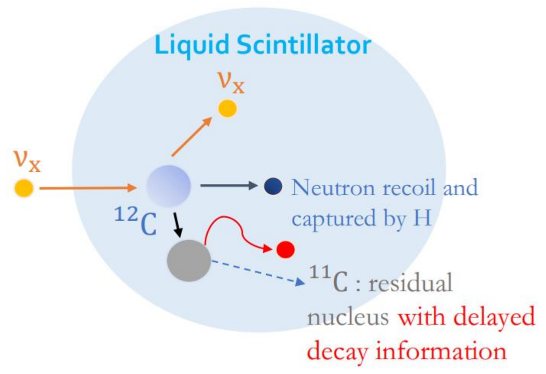
  intrinsic IBD events from **reactor** and **atmospheric $\bar{\nu}_e$**, and **cosmogenic ^{9}Li/ ^{8}He**

V. Background suppression (Event selection)

1. muon veto cut – in FV1 and FV2
2. pulse shape discrimination (PSD) – in FV1 and FV2
   - powerful tool to suppress atmospheric NC and fast neutron backgrounds
   - Based on time profiles of different particles in LS



3. triple-coincidence (TC) cut – only in FV1
   - Relied on the three-fold signature of the ^{11}C NC channel
   - Prompt signal: a fast neutron recoil
   - Delayed signal: neutron captured on hydrogen
   - Additional signal: from beta decay of the unstable ^{11}C nucleus
   - Apply time and distance cuts between the third delayed signal and the first prompt one

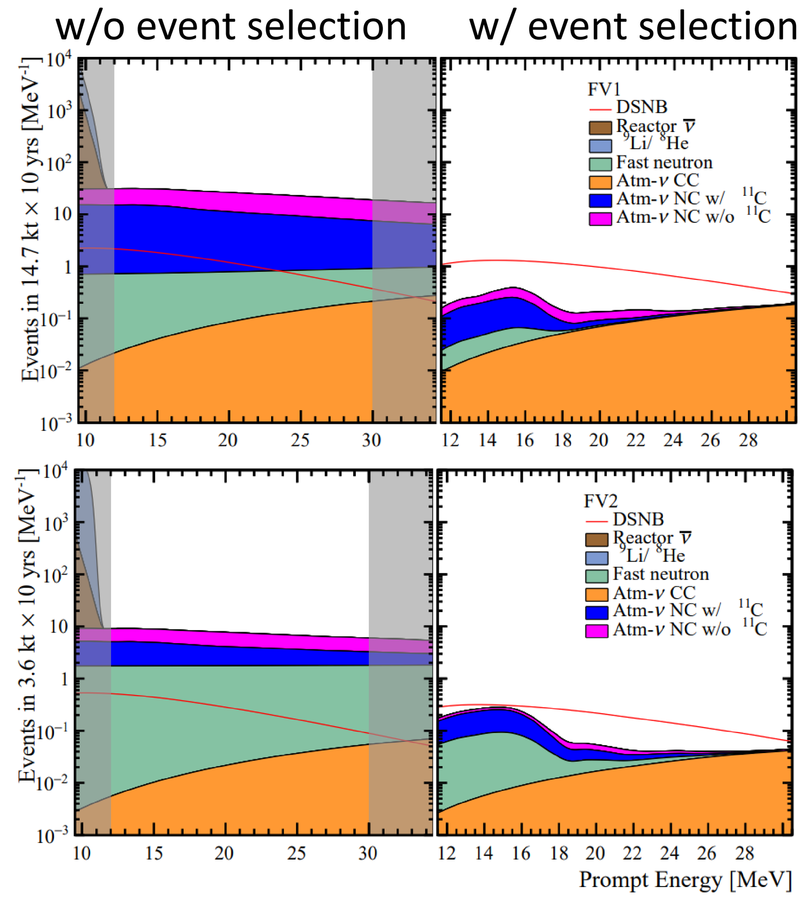


VI. DSNB sensitivity: discovery potential

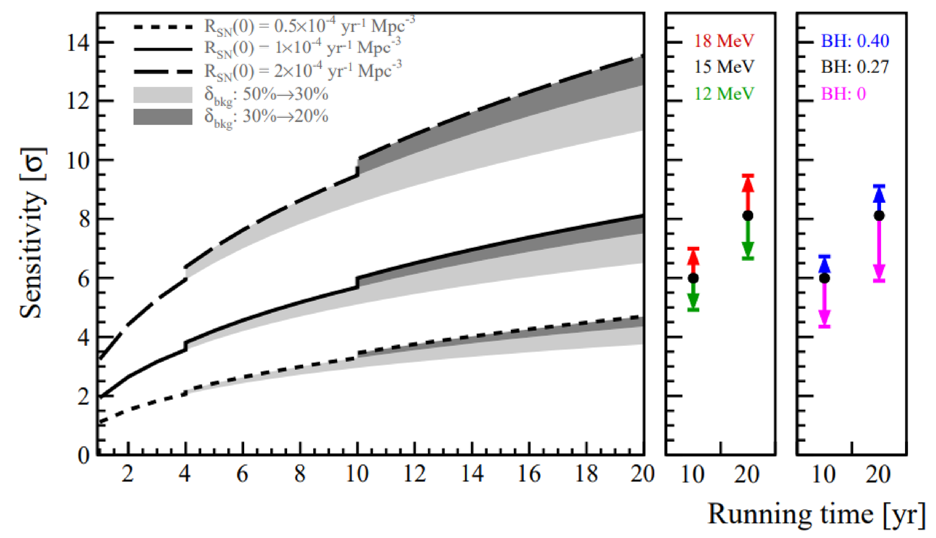
Signal/Background (S/B) ratio in observation window (12-30 MeV):

Rate (/(10 yrs))		w/o ES	w/ ES
FV1	DSNB	20.8	15.6
	Backgrounds	459.4	3.5
	S/B ratio	0.045	4.46
FV2	DSNB	5.0	3.6
	Backgrounds	136.5	1.9
	S/B ratio	0.037	2.0

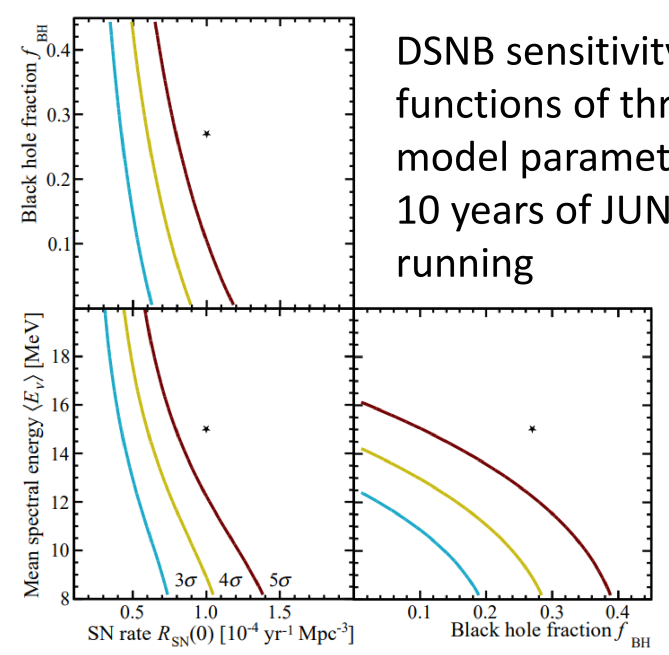
w/o event selection w/ event selection



Spectral fit is applied, using the Poisson likelihood function

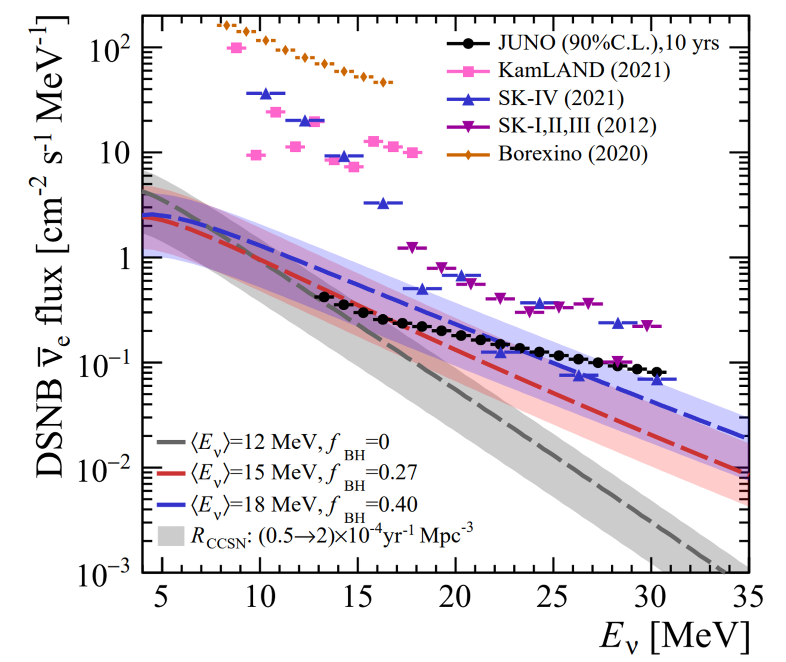


✓ Sensitivity as a function of the running time: 3σ @ 3yrs for the nominal model



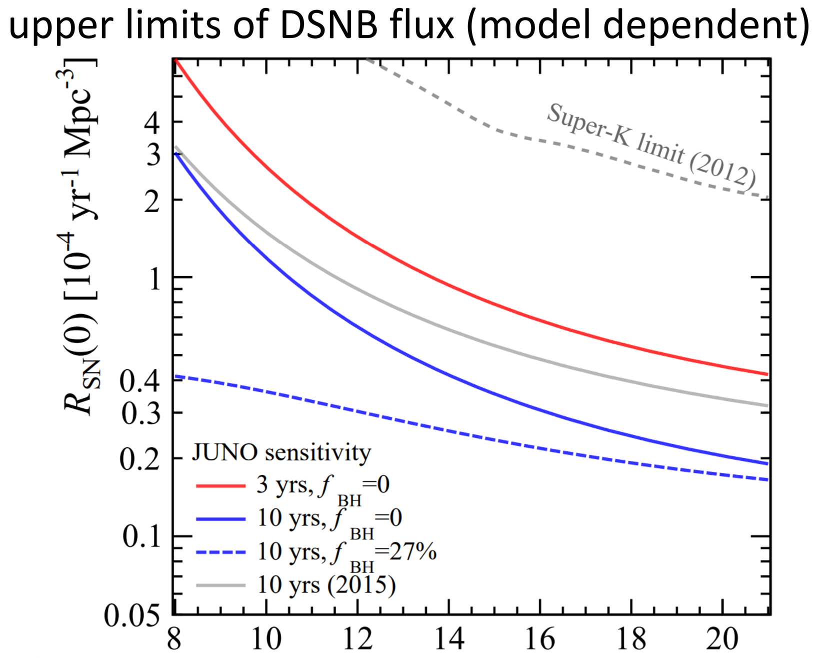
DSNB sensitivity as functions of three model parameters with 10 years of JUNO running

VII. DSNB sensitivity: exclusion limits



90% upper limit of DSNB flux (model independent)

90% upper limits of DSNB flux (model dependent)



VIII. Conclusions

- The PSD technique and TC cut can effectively suppress the NC background and achieve promising discovery potential.
- The DSNB discovery potential can be achieved 3σ after 3 years data taking and better than 5σ after 10 years for the nominal DSNB model.
- Even for the pessimistic scenario with non-observation, JUNO would strongly improve the latest best limits and exclude a significant region of the model parameter space.
- JUNO will start in 2023, enable a bright future of the DSNB physics within the next decade.