Detection of the Diffuse Supernova Neutrino Background with JUNO

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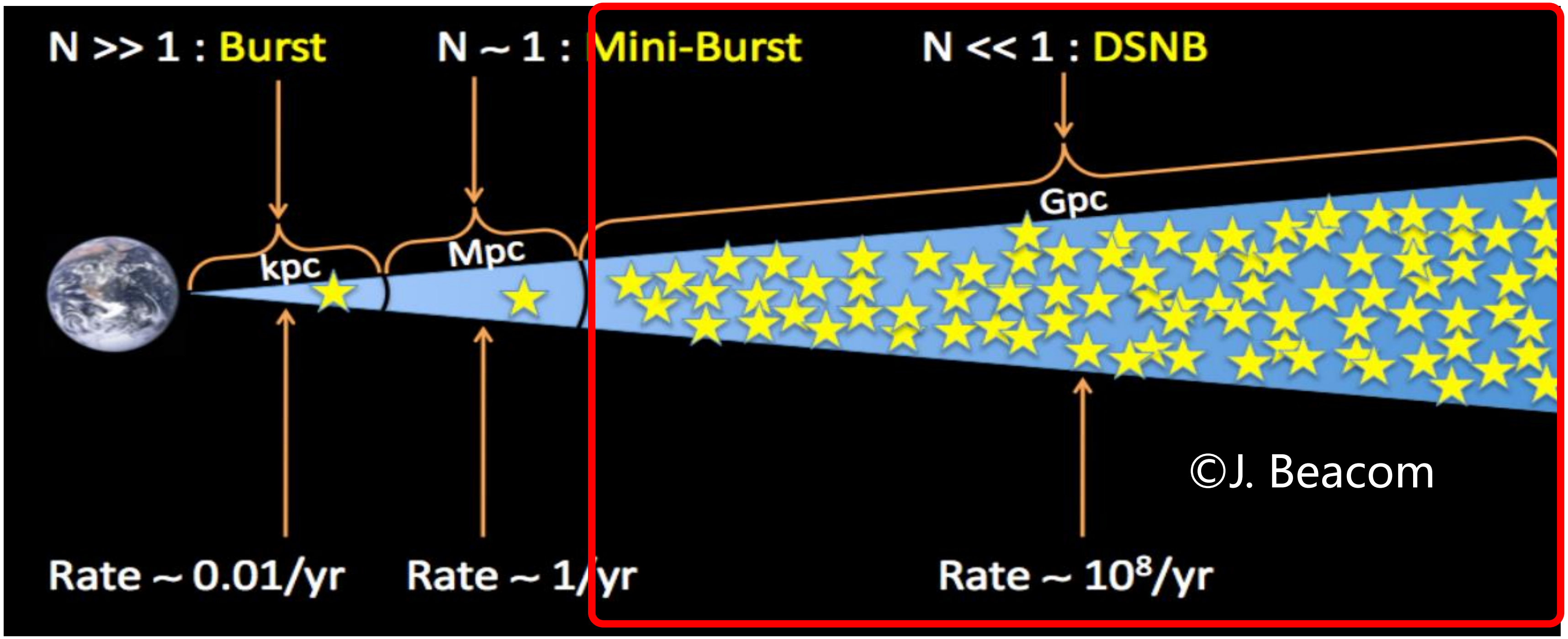
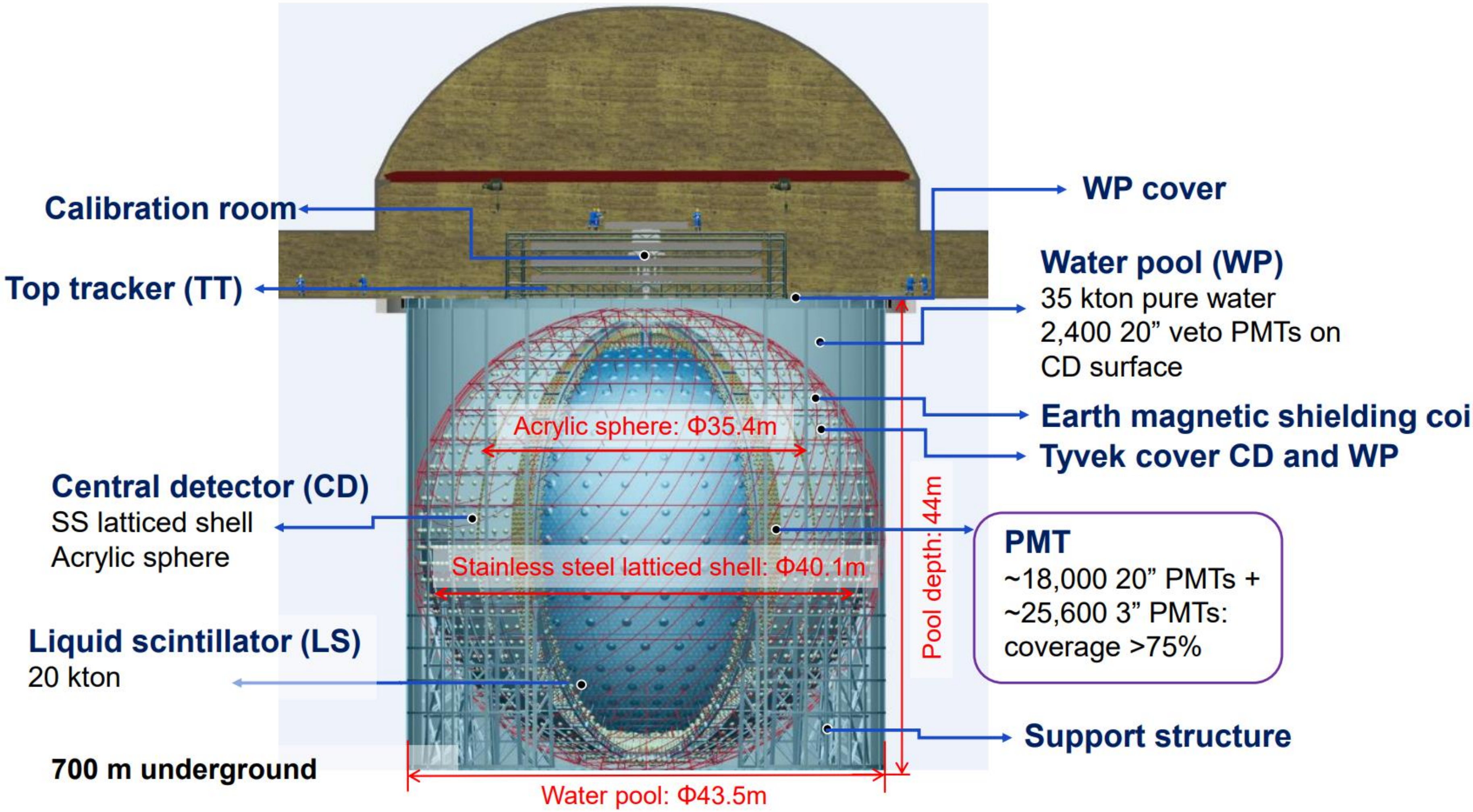
Diffuse supernova neutrino background



- Neutrino source: all past core-collapse supernovae
- Information: cosmic star-information, average core-collapse neutrino spectrum and failed SNe rate
- Detection: IBD in LS and water detector
- Key factors for DSNB:
  - Detector size (JUNO, SuperK-Gd, ...)
  - Background suppression

JUNO detector



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

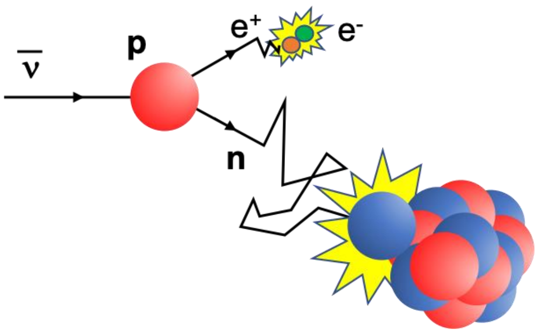
DSNB signal prediction

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

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

Prompt (positron, e^+) **Delayed** (neutron, n)

- JUNO: neutron captured in H



- **DSNB signal spectrum in detector:** Jacobian factor

Measured energy →

$$\frac{dS(E_{\mathrm{prompt}})}{dE_{\mathrm{prompt}}} = N_p \times \sigma(E_\nu) \times J(E_\nu) \times \frac{d\phi}{dE}(E_\nu)$$

→ **DSNB flux**

Detector capability

- **DSNB flux:**

$$\frac{d\phi}{dE_\nu} = \int_0^5 R_{\mathrm{SN}}(z) \frac{dN(E'_\nu)}{dE'_\nu}(1+z)\left|\frac{cdt}{dz}\right| dz$$

Average SN neutrino spectrum
- **Failed SNe**
- **Successful SNe**

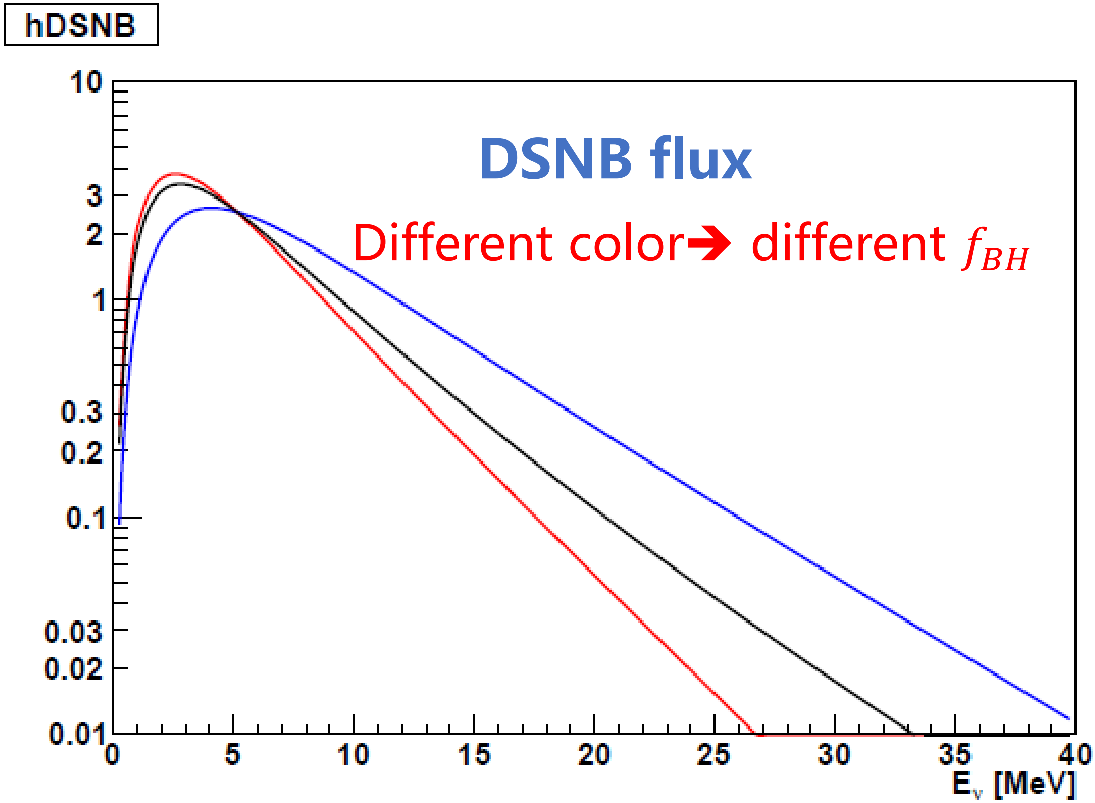
Core-collapse supernova rate at the red-shift *z*

DSNB signal prediction

Three uncertain parameters: $\langle E_\nu \rangle$, f_{BH}, $R_{SN}(0)$

- A reference set:
  - $\langle E_\nu \rangle = 15\text{MeV}$
  - $f_{BH} = 0.27$
  - $R_{SN}(0) = 1.0 \times 10^{-4}\text{yr}^{-1}\text{Mpc}^{-3}$

➡ **Scan of a broad parameter region for sensitivity study**

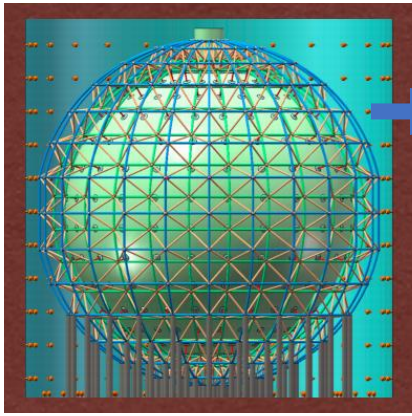


- **2-4 DSNB IBD events/year in JUNO**

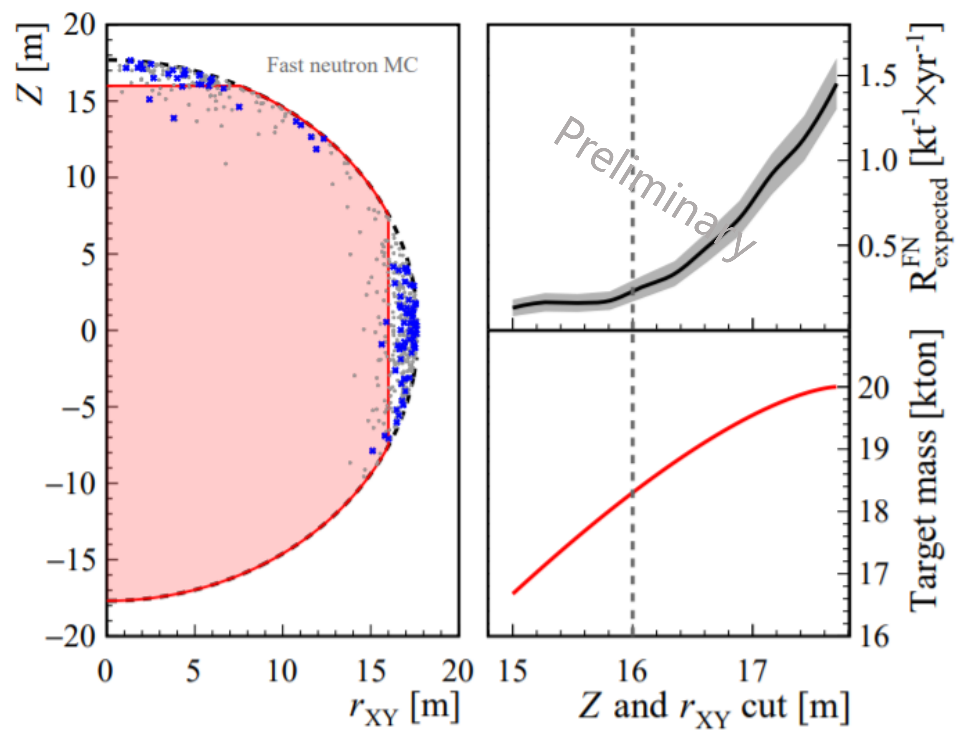
- **Backgrounds:**
  - Fast neutron
  - Atm-ν NC ➔ Most significant
  - Atm-ν CC
  - $^{9}Li/^{8}He$
  - reactor neutrino

Fast-neutron background

- **Fast neutron background ➔ fiducial volume**



Protective aquifer (water) ➔ shield the fast-neutron induced by untagged muon from rock



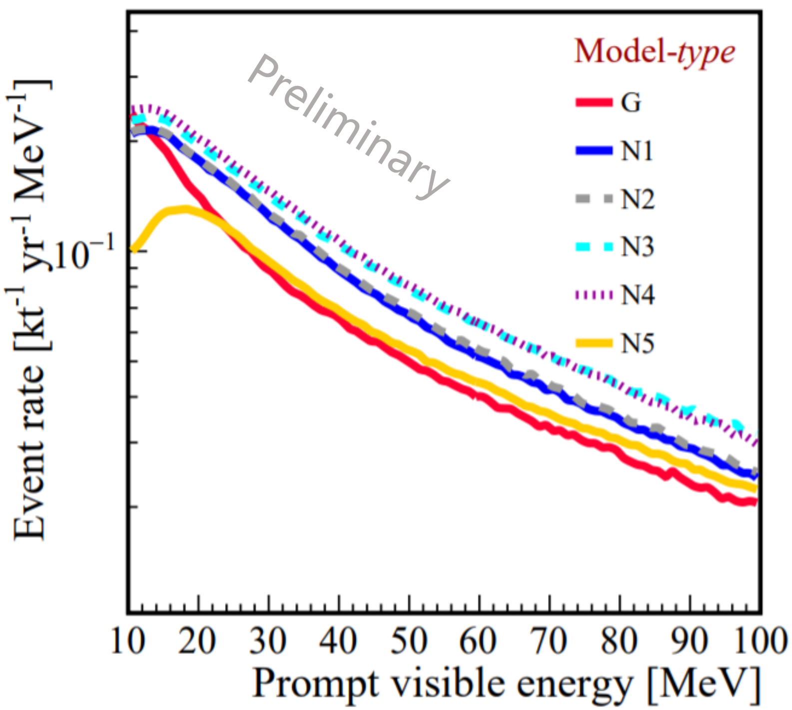
■ Red shade: fiducial volume

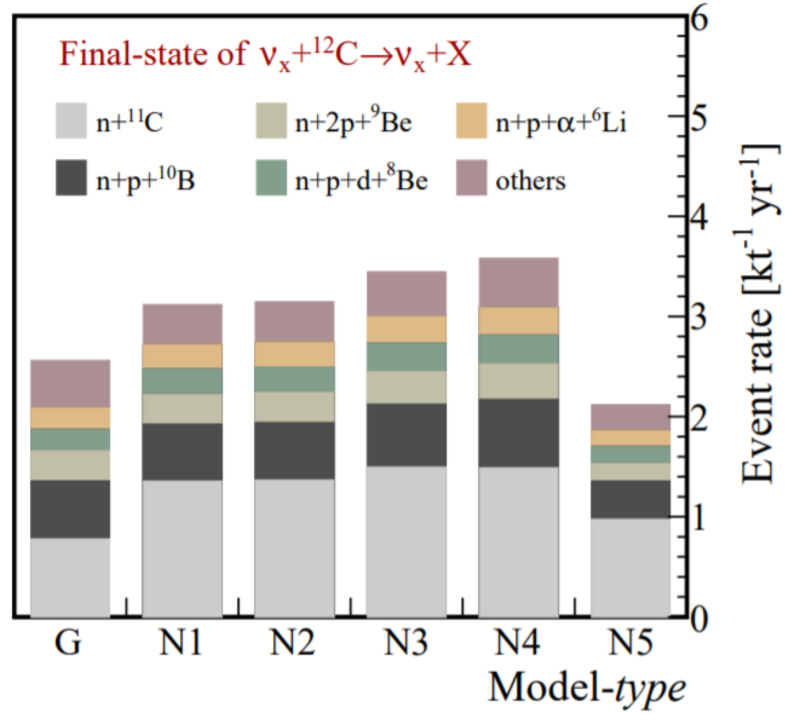
- ■ FV1 (inner region): R≡ $\sqrt{X^2+Y^2+Z^2}$<16m (14.7 kt)
- ■ FV2 (outer region): R>16m, Z and r_{XY} < 16m (3.6 kt)

Atmospheric neutrino NC background

- **Methods of model prediction from** *Phys.Rev.D* 103 (2021) 5, 053001

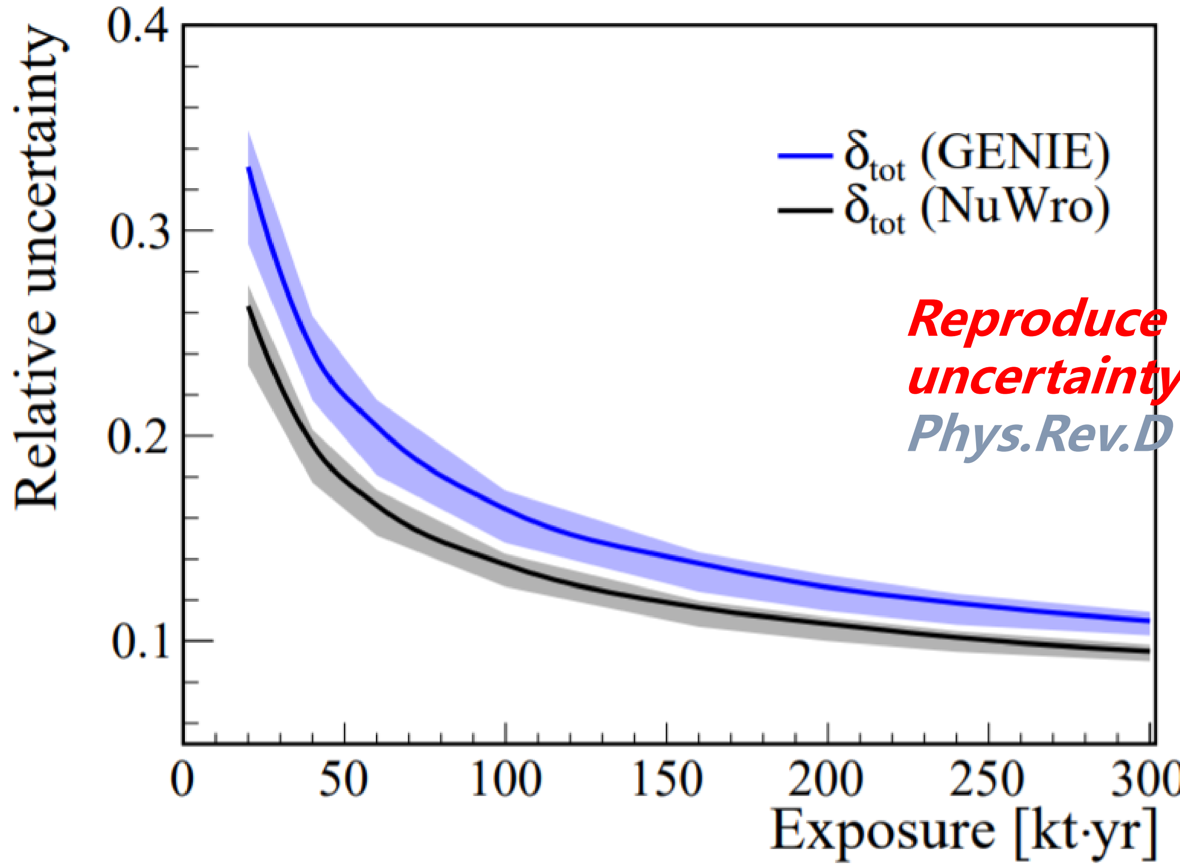
Dominant channels in [12, 30]MeV





- **Atm-ν flux:** taken from Prof. M. Honda (arXiv:1502.03916v2)
- **Neutrino interaction in LS:** Six data-driven models (GENIE and NuWro)
- De-excitation and decay processes of residual nuclei
- Predict NC background rate: $(3.0 \pm 0.5)\ \mathrm{yr}^{-1}\mathrm{kt}^{-1}$ in [12, 30]MeV

Uncertainty estimation of NC background



Reproduce NC background uncertainty from the summary in ***Phys.Rev.D*** **103 (2021) 5, 053002**

- Variations of different nuclear models ➔ 20% uncertainty
- Dominant channel: $\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + n + {}^{11}\mathrm{C}$ (triple-coincident signature)
- A maximum-likelihood method ➔ an *in situ* measurement
  - Within 10 years JUNO data, NC background rate can be constrained on 15% level

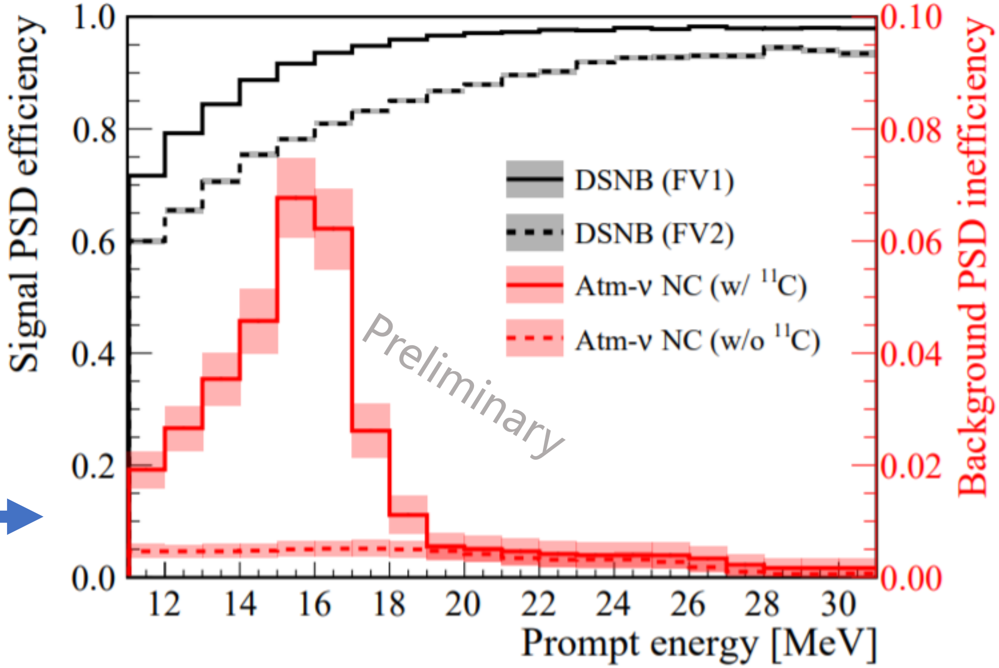
Background suppression

Pulse shape discrimination (PSD) ➔ powerful tool to suppress atmospheric NC and fast neutron backgrounds

- TMVA-based multi-variate analysis
- Peak shape, tail shape and position dependency as inputs
- Energy-dependent PSD

[12, 30] MeV:

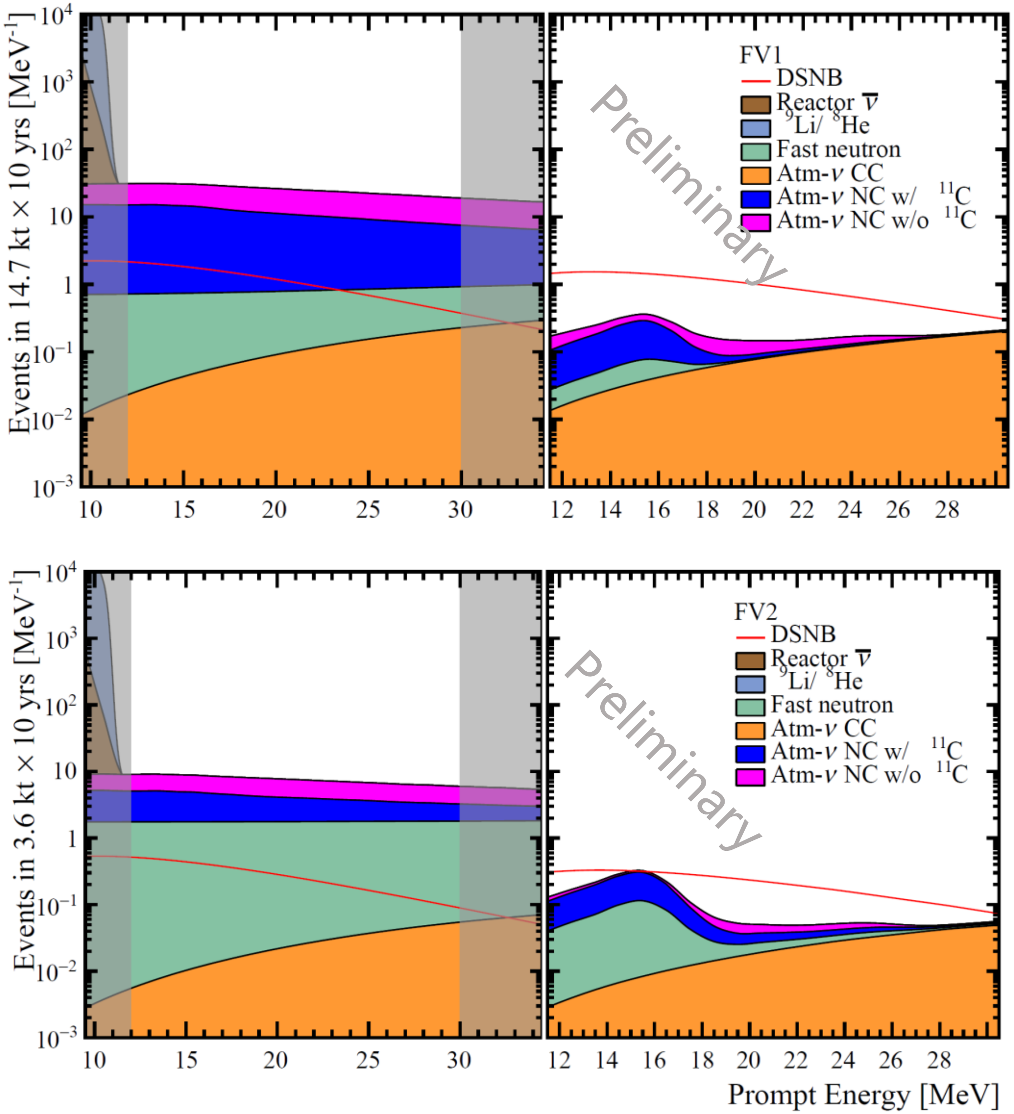
- **The average residual level of NC background: 1% (~0.03 $yr^{-1}kt^{-1}$)**
- **Average DSNB signal efficiency:**
  - **FV1: 91%**
  - **FV2: 80%**



- **PSD uncertainty estimation via possible similar data samples**

Final rates and spectra of signal and background

w/o event selection — w/ event selection



Event selection (ES):

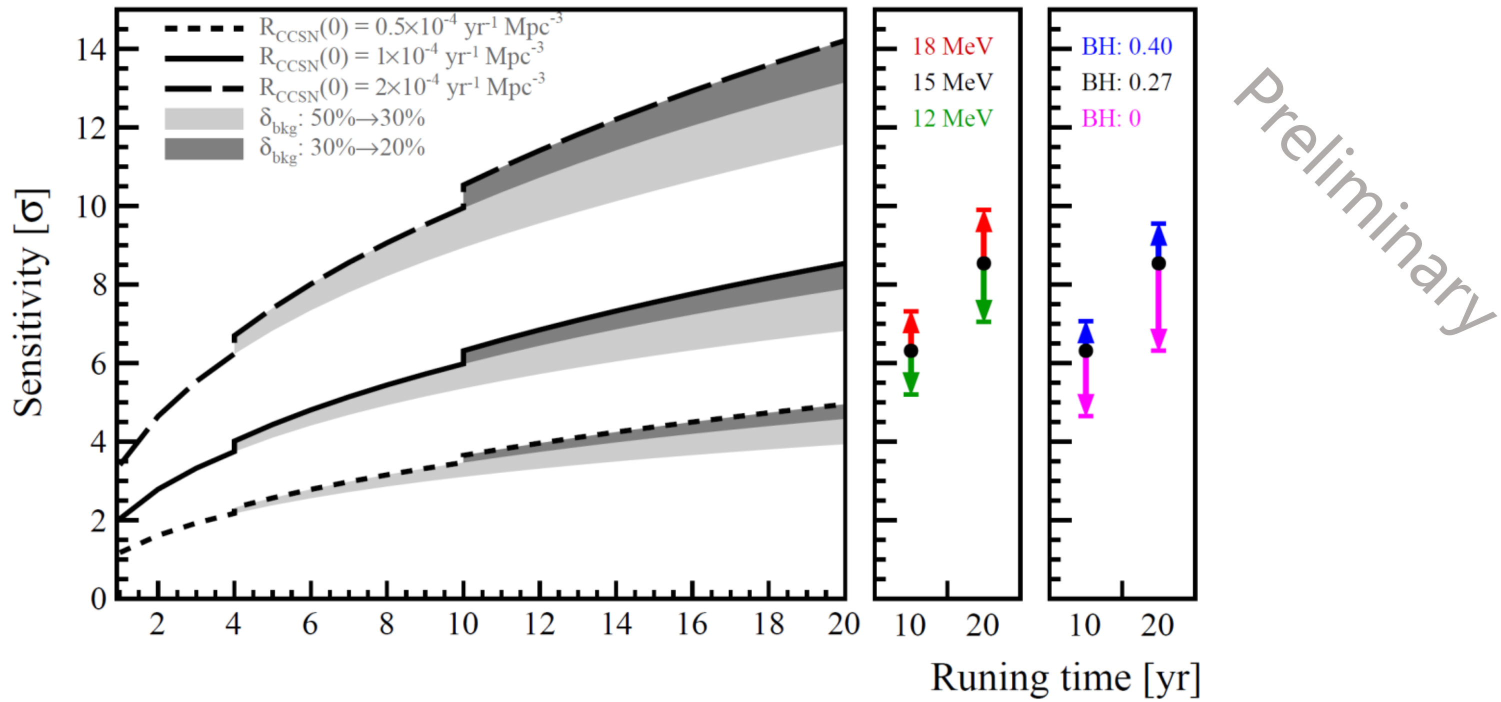
- Muon veto and energy-dependent PSD cut (page.9) for FV1 and FV2
- Triple-coincident cut for NC (w/^{11}C) for FV1
  - independent of the prompt spectra
  - relied on the decay information of ^{11}C
- Observation window for prompt events: [12, 30]MeV

S/B ratio in observation window:

	w/o ES	w/ ES
FV1	0.045	4.76
FV2	0.037	2.04

Model-dependent sensitivity

- **Discovery significance for the DSNB signals (spectral fit)**



Exposure	1-3 years	4-9 years	10-20 years
NC Background uncertainty (Plot in Page.8)	35%	25%	15%
PSD uncertainty	40%	20%	10%
Total uncertainty	50%	30%	20%

Summary

- JUNO has great potential to detect the DSNB with its 20 kt LS
- The dominant background: NC interaction of atmospheric neutrinos with ^{12}C
  - Surpasses the DSNB by more than one order of magnitude
  - The NC background is evaluated from the spread of a variety of data-driven models
  - A novel method of *in situ* measurement to determine NC background within 15% with 10 years of JUNO data
  - NC-like backgrounds can be effectively suppressed by the PSD of LS

- The DSNB discovery potential can be achieved 3σ after 3 years data taking assuming the reference model of DSNB and 50% background uncertainty

- The DSNB paper will be published soon
- JUNO will finish the detector installation at 2022

Thanks!