Sensitivity to invisible modes of neutron decay on JUNO

Cailian Jiang

cailianjiang@smail.nju.edu.cn

Poster ID: 324

Cailian Jiang[1], Yuxiang Hu[2] *On behalf of the JUNO collaboration*

[1]NanJing University, [2]Institute of High Energy Physics

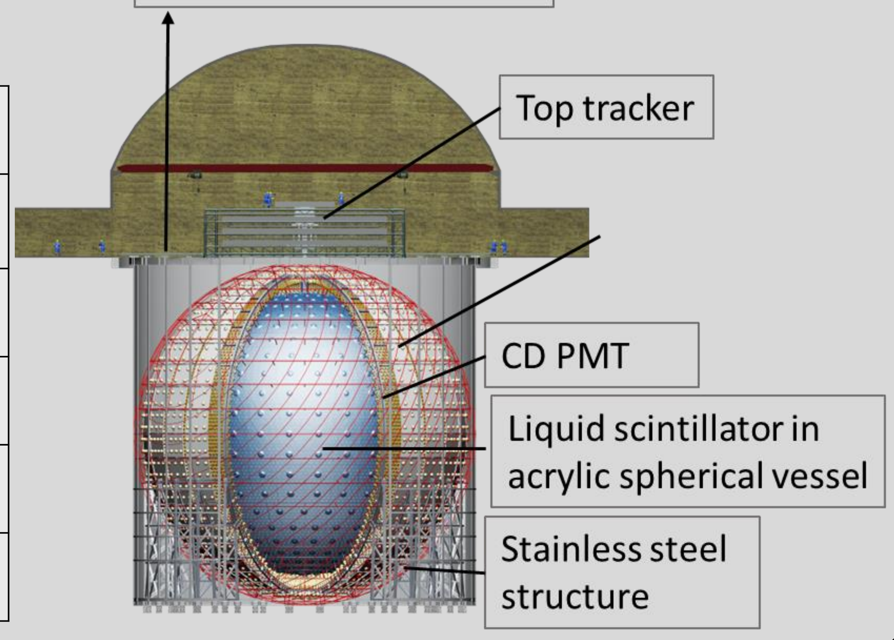
1. JUNO experiment

Jiangmen Underground Neutrino Observatory (JUNO)

Multi-purpose medium baseline reactor neutrino experiment[1]

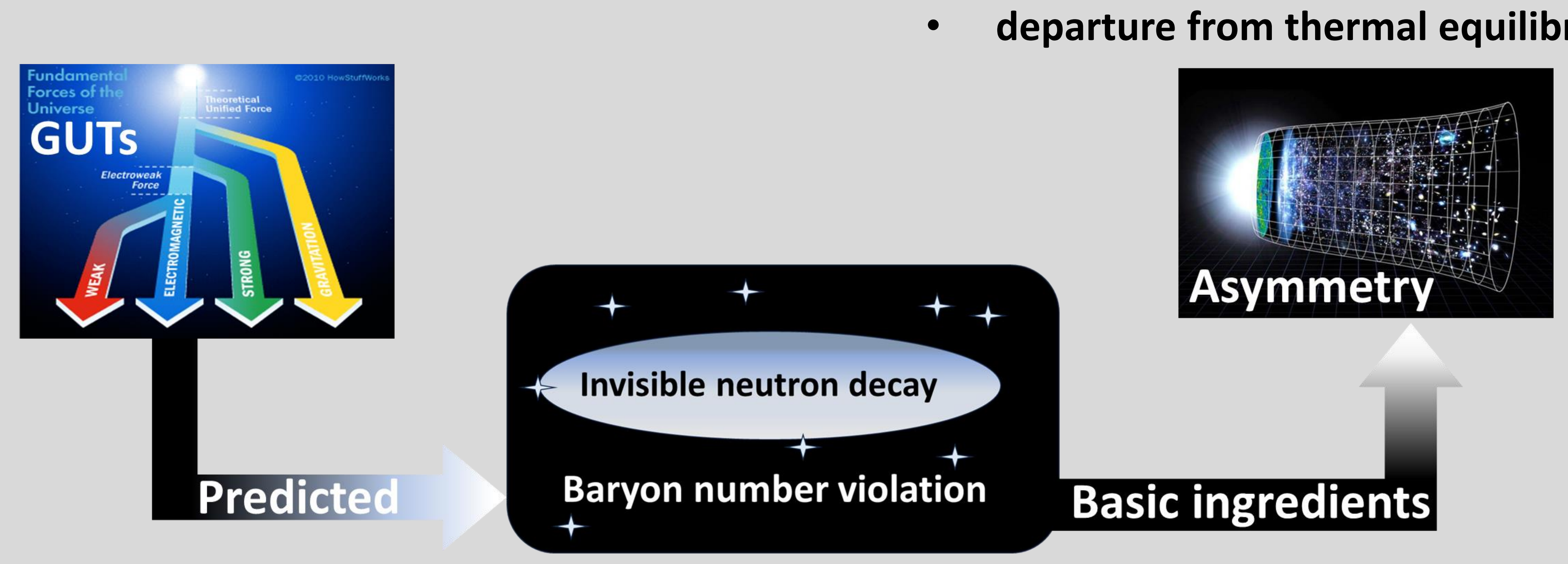
- Physics goals:
  - Neutrino mass ordering
  - Solar neutrino, atmospheric neutrino, supernova neutrino…
  - new physics
    - nucleon decay searches

Photon Statistics	1665 p.e./MeV
PMT coverage	77%
LS transparency	> 20 m
Light yield(anthracene)	45%
Detection Eff.(QE×CE)	30%
Target mass	20 kt



2. Motivation

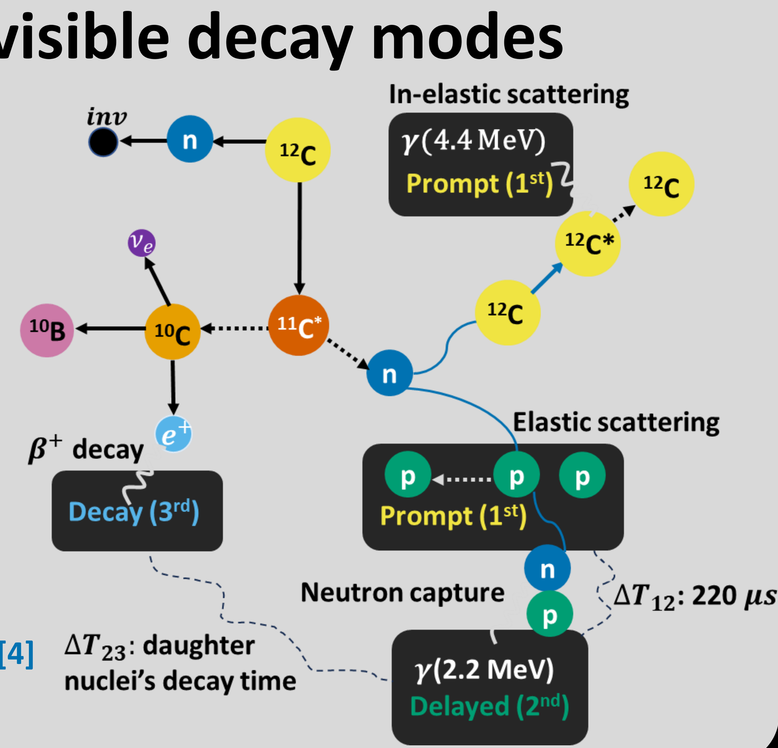
- Predict the instability of nucleon[2]
  - Nucleon can decay into lighter subatomic particles
  - Invisible modes of neutron decay
    - neutron decay into undetected particles
  - Search nucleon decay to test GUTs
- Matter-antimatter is asymmetric in universe
  - Sakharov conditions[3]
    - *explain the asymmetry*
    - Baryon number violation $\Delta B \neq 0$
    - C and CP violation
    - departure from thermal equilibrium



3. Invisible Neutron Decay Search in JUNO

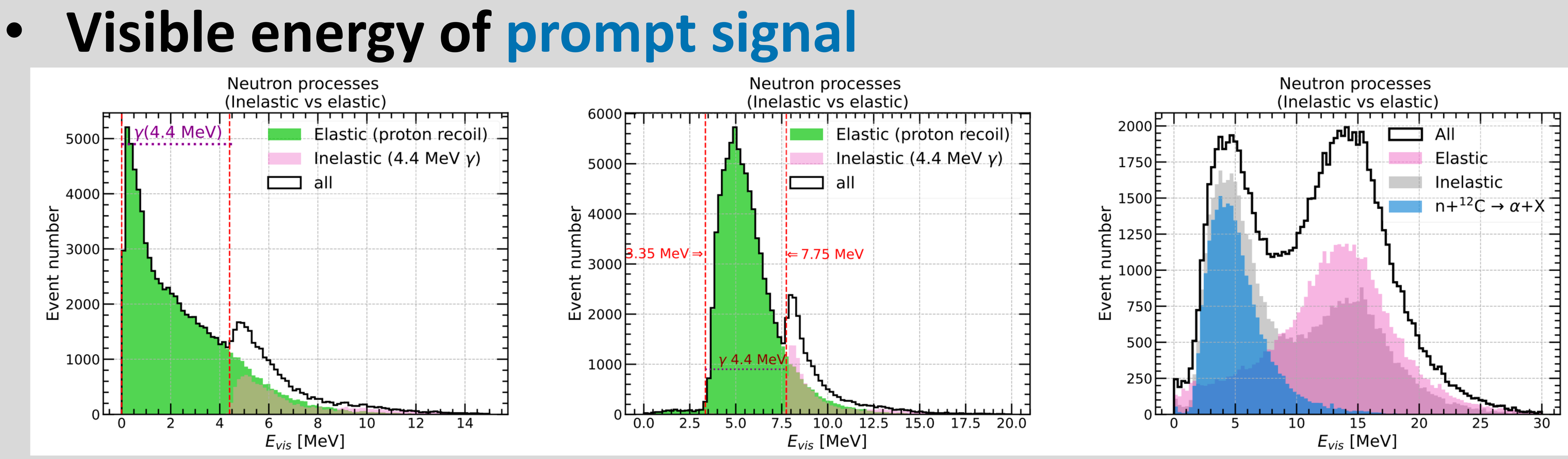
- Bounded neutrons in ^{12}C : two invisible decay modes
  - $n \rightarrow invisible$ $(^{12}C \rightarrow {}^{11}C^*)$
  - $nn \rightarrow invisible$ $(^{12}C \rightarrow {}^{10}C^*)$
- De-excitation modes in LS
  - $^{11}C^* \rightarrow n + {}^{10}C\ (Br_{n1} = 3.0\%)$
  - $^{11}C^* \rightarrow n + \gamma + {}^{10}C\ (Br_{n2} = 2.8\%)$
  - $^{10}C^* \rightarrow n + {}^{9}C\ (Br_{nn1} = 6.2\%)$
  - $^{10}C^* \rightarrow n + p + {}^{8}B\ (Br_{nn2} = 6.0\%)$

Above modes can form triple coincidence signals[4]



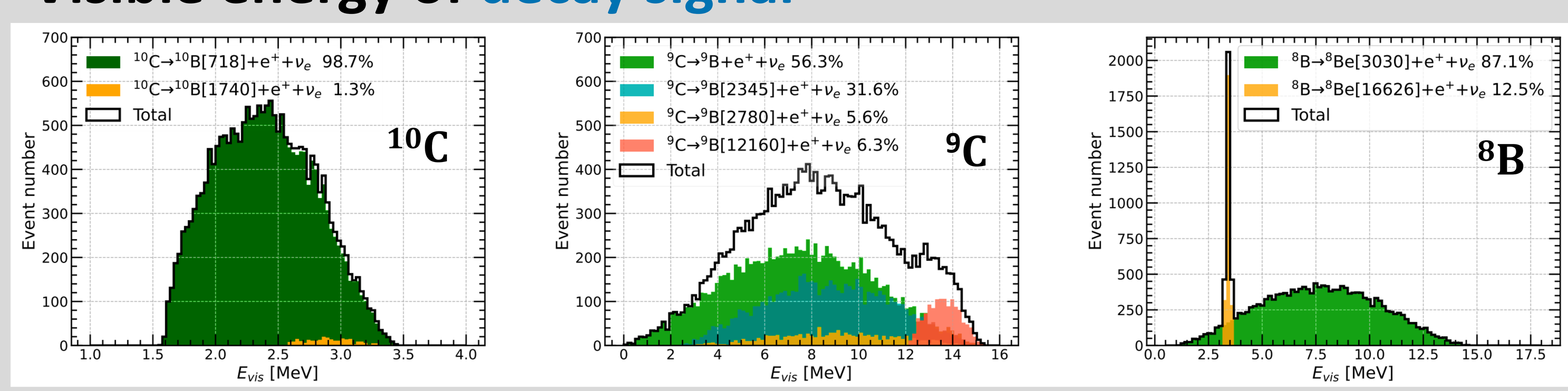
4. Signal

- Visible energy of prompt signal

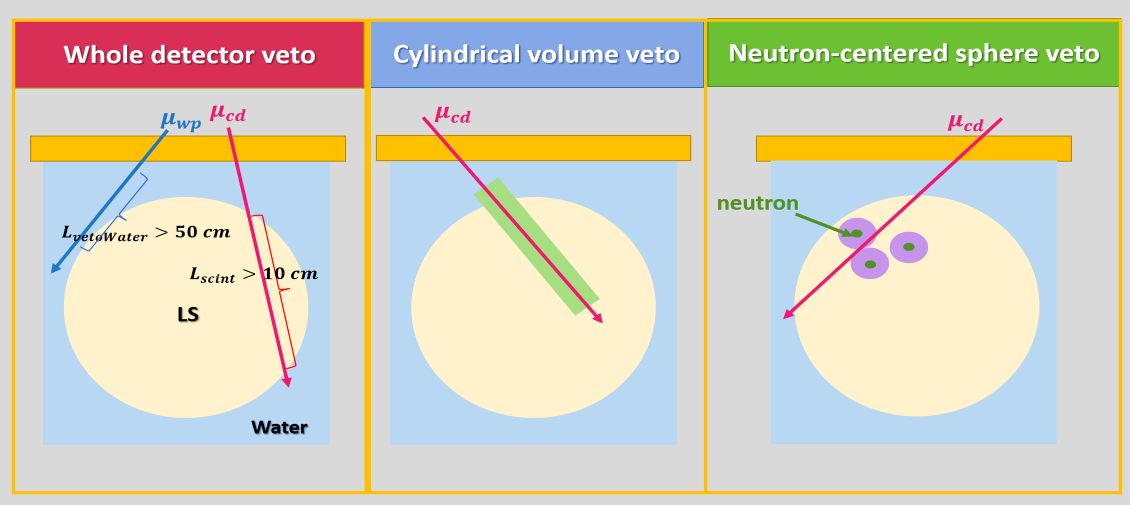


$^{11}C^* \rightarrow n + {}^{10}C$ $\quad$ $^{11}C^* \rightarrow n + \gamma + {}^{10}C$ $\quad$ $^{10}C^* \rightarrow n + {}^{9}C$, $^{10}C^* \rightarrow n + p + {}^{8}B$

- Visible energy of decay signal



- Event selection
  - Muon veto and Basic event selection



Quantity	$n \rightarrow inv$	$nn \rightarrow inv$
$R_{1,2,3}$ [m]	< 16.7	< 16.7
E_1 [MeV]	0.7-12	0.7-30
E_2 [MeV]	1.9-2.5	1.9-2.5
E_3 [MeV]	1.5-3.5	3.0-16.0
ΔT_{12} [ms]	< 1	< 1
ΔT_{23} [s]	0.002-100	0.002-3.0
ΔR_{12} [m]	< 1.5	< 1.5
ΔR_{23} [m]	< 1.5	< 1.5
ΔR_{13} [m]	< 1.0	< 1.0

5. Backgrounds

Background source

- Single
  - Radioactivity, Long-lived isotopes
- Correlated (Prompt-Delayed)
  - IBD (Inverse Beta decay), Li9/He8, Fast neutron, Alpha-n, $Atm - \nu$ NC
- Triple (Prompt-Delayed-Decay)
  - $Atm - \nu$ NC

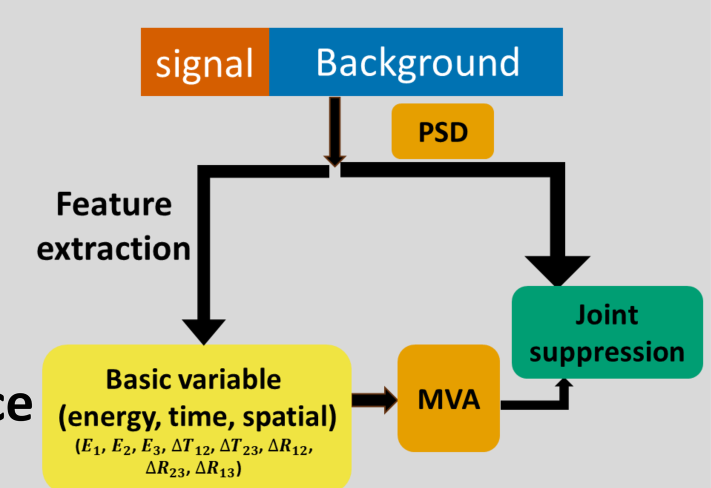
Triple:
- Single + Single + Single
- Correlated + Single

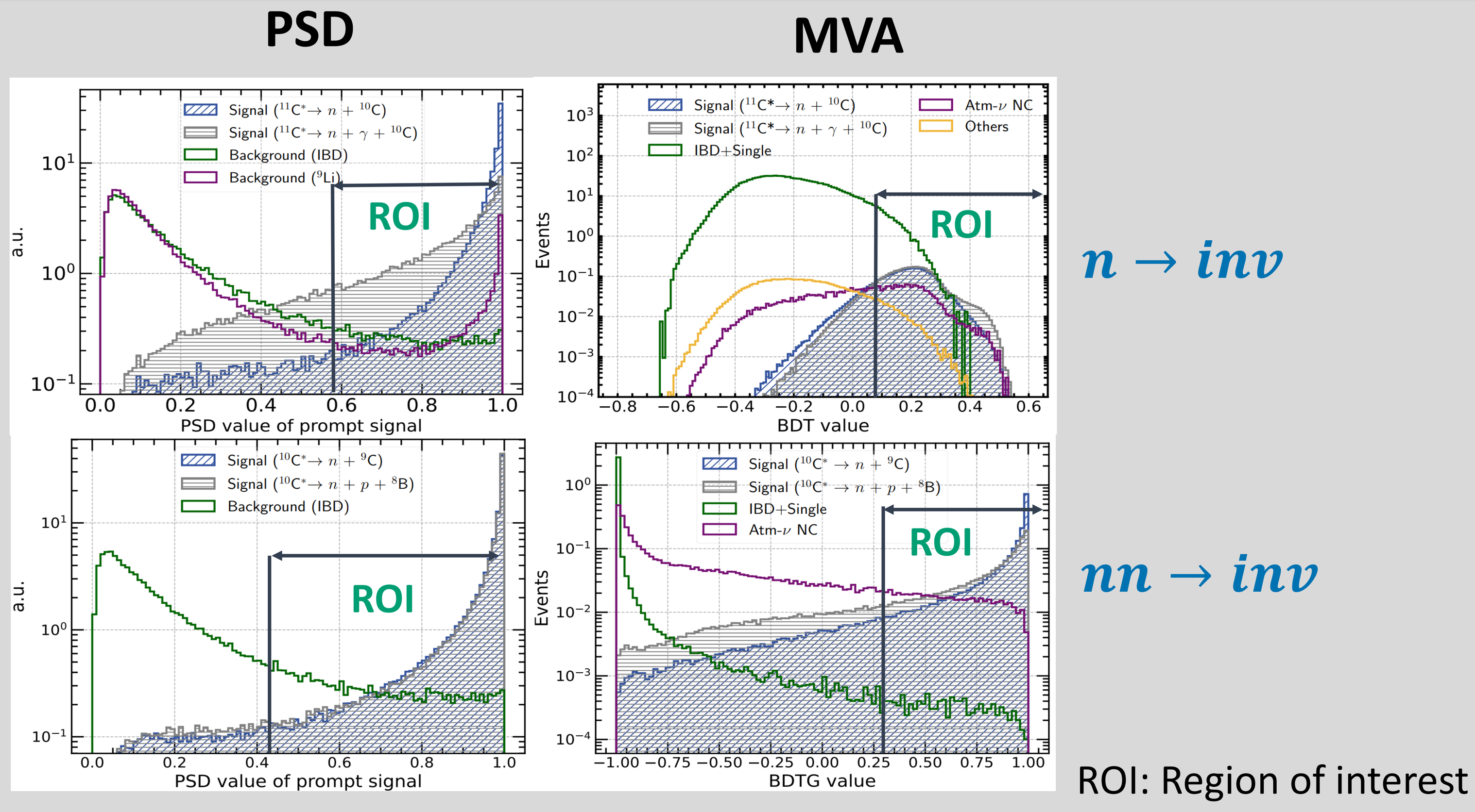
$$\nu/\bar{\nu} + {}^{12}C \rightarrow \nu/\bar{\nu} + n + {}^{11}C\,,$$
$$\nu/\bar{\nu} + {}^{12}C \rightarrow \nu/\bar{\nu} + 2n + {}^{10}C\,,$$
$$\nu/\bar{\nu} + {}^{12}C \rightarrow \nu/\bar{\nu} + 3p + n + {}^{8}Li$$

$$\nu/\bar{\nu} + {}^{12}C \rightarrow \nu/\bar{\nu} + n + p + {}^{10}B\,,$$
$$\nu/\bar{\nu} + {}^{12}C \rightarrow \nu/\bar{\nu} + n + p + \alpha + {}^{6}Li\,,$$
$$\nu/\bar{\nu} + {}^{12}C \rightarrow \nu/\bar{\nu} + n + 2p + {}^{9}Be\,,$$
$$\nu/\bar{\nu} + {}^{12}C \rightarrow \nu/\bar{\nu} + n + p + d + {}^{8}Be\,.$$

Background suppression

- Combine two suppression method
  - Pulse Shape Discrimination
    - Particle's emission photon time are different
  - Multi Variate Analysis
    - Combine multidimensional features
  - Both PSD and MVA have good performance
    - Effectively suppress background



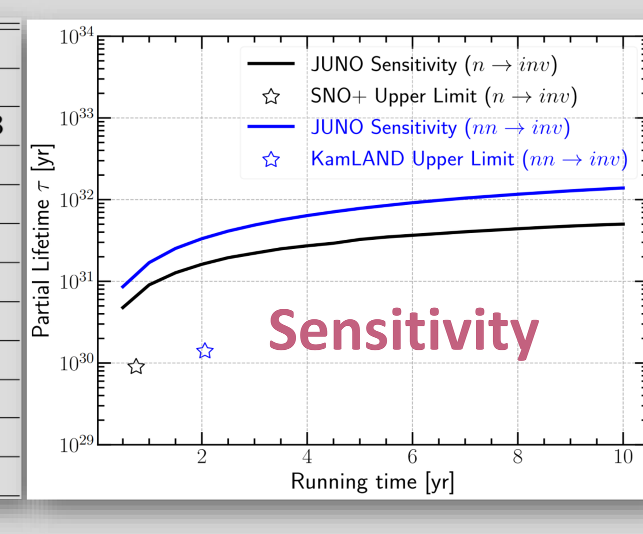


ROI: Region of interest

6. Sensitivity and Conclusion

- Consider 10 years' JUNO data taking

Backgrounds (10 years)	$n \rightarrow inv$		$nn \rightarrow inv$	
	Basic selection	PSD + MVA	Basic selection	PSD + MVA
IBD + Single	1235 ± 50	2.72 ± 0.10	3.01 ± 0.09	0.0110 ± 0.0003
Atm-ν NC	3.0 ± 1.1	0.93 ± 0.67	4.3 ± 3.5	0.55 ± 0.63
$^{13}C(\alpha,n)^{16}O$ + Single	3.4 ± 1.4	0.036 ± 0.013	–	–
$^{9}Li/^{8}He$ + Single	1.55 ± 0.39	0.29 ± 0.17	0.13 ± 0.13	0.13 ± 0.13
Accidental	1.46 ± 0.05	0.095 ± 0.004	–	–
Total	1244 ± 50	4.07 ± 0.68	7.4 ± 3.5	0.69 ± 0.64
Signal efficiency (%)	$n \rightarrow inv$		$nn \rightarrow inv$	
	Basic selection	PSD + MVA	Basic selection	PSD + MVA
$\epsilon_{n(nn)1}$	35.6 ± 0.2	23.5 ± 0.2	54.0 ± 0.3	48.2 ± 0.3
$\epsilon_{n(nn)2}$	43.6 ± 0.3	30.3 ± 0.3	49.2 ± 0.3	36.3 ± 0.3



$\tau/B(n \rightarrow inv) > 5.0 \times 10^{31}$ year at 90% C.L.

$\tau/B(nn \rightarrow inv) > 1.4 \times 10^{31}$ year at 90% C.L.

An order of magnitude improvement to current best limits with 2 years data taking

7. References

[1] F. An et al. [JUNO] J. Phys. G 43, no.3, 030401 (2016).
[2] P. Nath and P. Fileviez Perez, Phys. Rept. 441, 191-317 (2007).
[3] A. D. Sakharov, Sov. Phys. Usp. 34, 392 (1991).
[4] Y. A. Kamyshkov and E. Kolbe, Phys. Rev. D 67, 076007 (2003).

JUNO Sensitivity to Invisible Decay Modes of Neutrons *arXiv:2405.17792*