On the prospect of JUNO detections of MeV neutrinos from low-mass dark matter (DM) annihilation in the galactic halo

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Outline

- Introduction: what has been discussed in the yellowbook and what is new here.
- MeV neutrinos from DM annihilations in the galactic halo and backgrounds
- Signal and background event rates in JUNO
- Summary

Introduction

What has been proposed in the yellowbook?

- Propose to search for neutrino signature from DM annihilation in the Sun.
- This study is sensitive to DM-nucleon cross section
- Focusing on detecting muon neutrinos since the resulting muon tracks give directional information

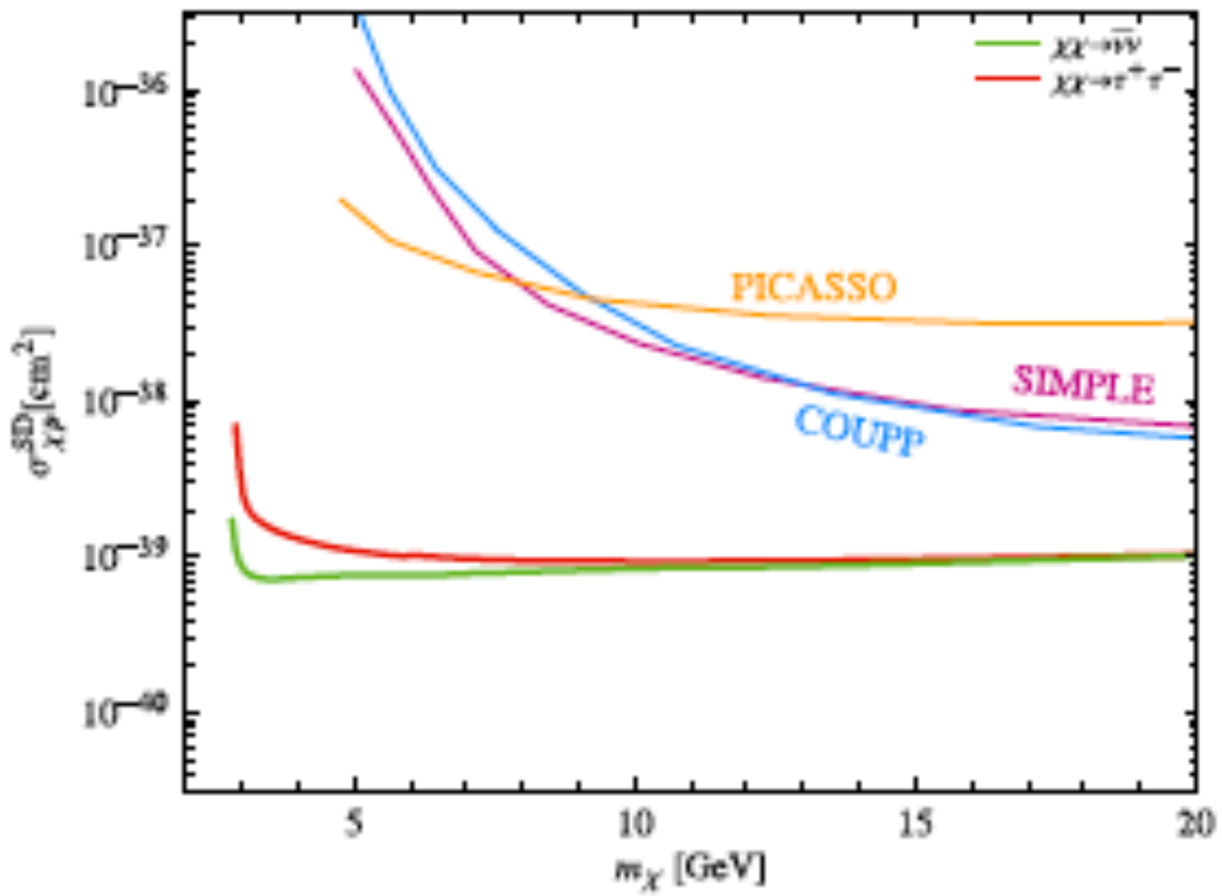


Figure 81. The JUNO 2σ sensitivity in 5 years to the spin-dependent cross section $\sigma_{\chi p}^{SD}$ in 5 years. The constraints from the direct detection experiments are also shown for comparison.

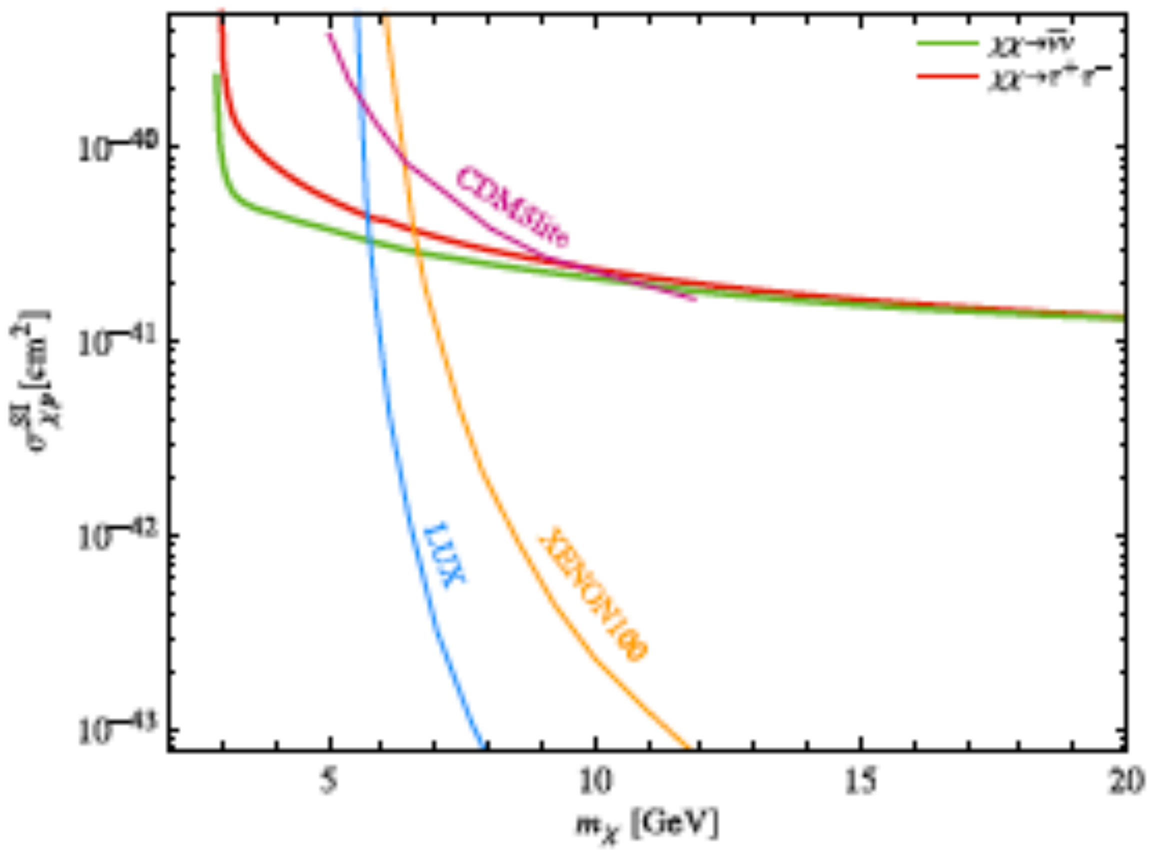


Figure 82. The JUNO 2σ sensitivity in 5 years to the spin-independent cross section $\sigma^{SI}_{\chi p}$. The recent constraints from the direct detection experiments are also shown for comparison.

See also study in
W. L. Guo, JCAP 1601 (2016) no.01, 039

Since DM would evaporate from the Sun for DM mass less than 5 GeV, this approach cannot probe DM with MeV level masses.

MeV neutrinos from DM annihilations in the galactic halo

$$\chi\chi \to \nu\bar{\nu}$$

The differential neutrino and anti-neutrino flux for each flavor

$$\frac{d\phi}{dE_\nu} = \frac{\langle\sigma_A v\rangle}{2}\mathcal{J}_{\rm avg}\frac{R_{\rm sc}\rho_0^2}{m_\chi^2}\frac{1}{3}\delta(E_\nu - m_\chi)$$

R_{sc}=8.5 kpc is the solar radius circle

$$\mathcal{J}_{\rm avg} = \frac{1}{2R_{\rm sc}\rho_0^2}\int_{-1}^{1}\int_0^{l_{\rm max}}\rho^2(r)dld(\cos\psi)$$

Angular-averaged line of sight integration-profile information

S. Palomares-Ruiz and S. Pascoli, Phys. Rev. D 77, 025025 (2008)

The flavor transition of neutrinos from source to the terrestrial detector is given by the matrix

$$P(\nu_\beta \to \nu_\alpha) \equiv P_{\alpha\beta}$$

- We only consider electron anti-neutrino flux detected by IBD process
- The matrix elements are calculated with best-fit values of neutrino mixing parameters given in PDG 2016

NH	IH
$P_{ee} = 0.56$	$P_{ee} = 0.56$
$P_{e\mu} = 0.24$	$P_{e\mu} = 0.17$
$P_{e\tau} = 0.20$	$P_{e\tau} = 0.27$
$P_{\mu\mu} = 0.38$	$P_{\mu\mu} = 0.45$
$P_{\mu\tau} = 0.38$	$P_{\mu\tau} = 0.38$
$P_{\tau\tau} = 0.42$	$P_{\tau\tau} = 0.35$

Backgrounds

- Reactor anti-neutrinos:~800 events per kt.yr in JUNO. It can be controlled by choosing the threshold of visible energy ~11MeV
- Cosmogenic isotopes: this background can be controlled in the same way as the above
- Charged-current interaction atmospheric electron anti-neutrinos: irreducible background
- Neutral-current interaction of atmospheric neutrinos: very important background overlooked by earlier papers.

Reaction channel	Branching ratio
(1) $\nu_x + {}^{12}C \rightarrow \nu_x + n + {}^{11}C$	38.8%
(2) $\nu_x + {}^{12}C \rightarrow \nu_x + p + n + {}^{10}B$	20.4%
(3) $\nu_x + {}^{12}C \rightarrow \nu_x + 2p + n + {}^{9}Be$	15.9%
(4) $\nu_x + {}^{12}C \rightarrow \nu_x + p + d + n + {}^{8}Be$	7.1%
(5) $\nu_x + {}^{12}C \rightarrow \nu_x + \alpha + p + n + {}^{6}Li$	6.6%
(6) $\nu_x + {}^{12}C \rightarrow \nu_x + 2p + d + n + {}^{7}Li$	1.3%
(7) $\nu_x + {}^{12}C \rightarrow \nu_x + 3p + 2n + {}^{7}Li$	1.2%
(8) $\nu_x + {}^{12}C \rightarrow \nu_x + d + n + {}^{9}B$	1.2%
(9) $\nu_x + {}^{12}C \rightarrow \nu_x + 2p + t + n + {}^{6}Li$	1.1%
(10) $\nu_x + {}^{12}C \rightarrow \nu_x + \alpha + n + {}^{7}Be$	1.1%
(11) $\nu_x + {}^{12}C \rightarrow \nu_x + 3p + n + {}^{8}Li$	1.1%
other reaction channels	4.2%

Möllenberg R, von Feilitzsch F, Hellgartner D, Oberauer L, Tippmann M, Zimmer V, Winter J and Wurm M 2015 Phys. Rev. D 91 032005

- The knock-out neutrons which mimic positrons in the prompt signal can be identified by applying pulse shape analysis.
- Using the result by R. Möllenberg et al. for LENA, one has the following efficiency factors for signal and background events:

The efficiencies due to PSD

Signal and atmospheric CC background $\epsilon_\nu = 50\%$

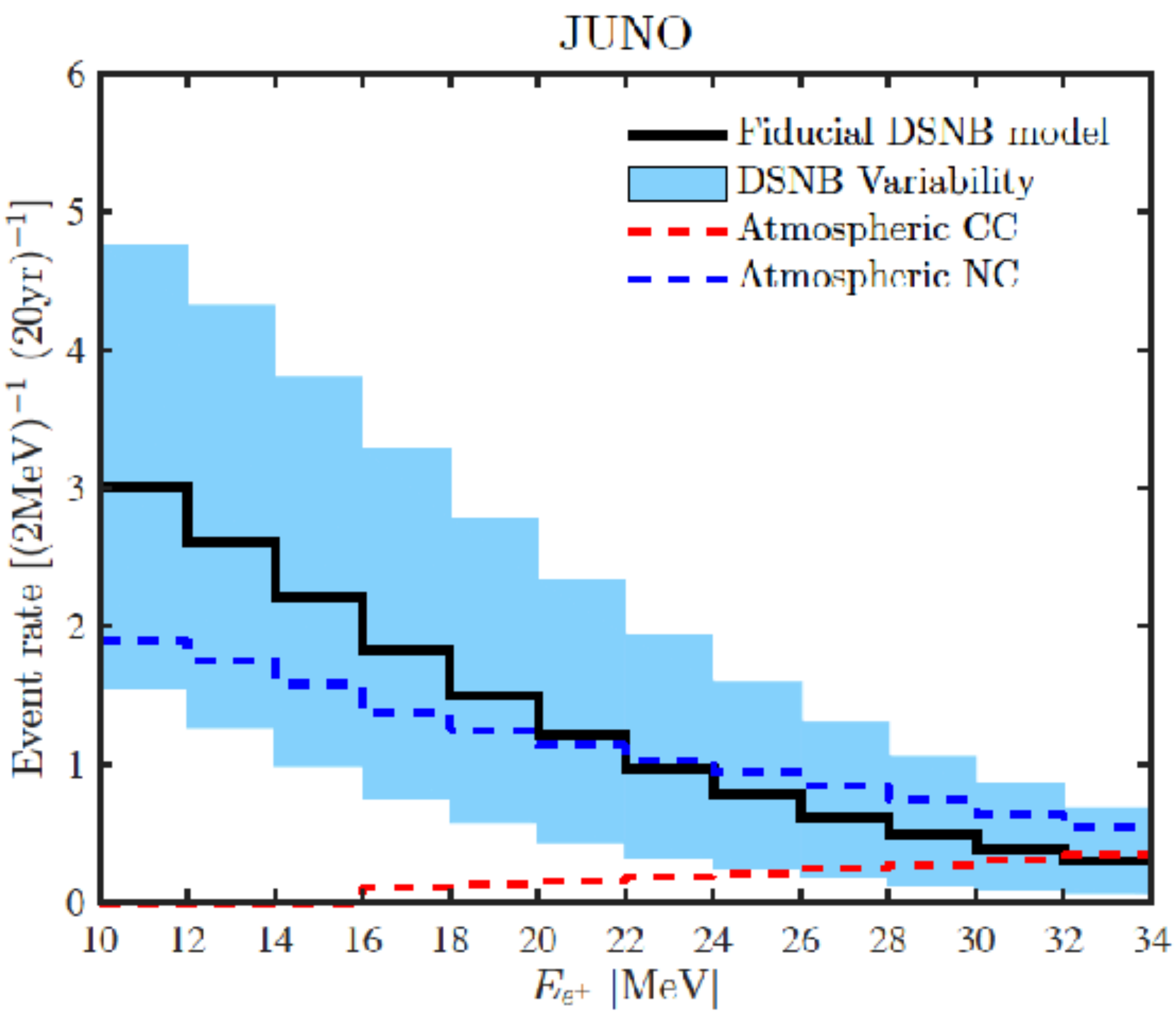
Atmospheric NC background $\epsilon_{NC} = 1.1\%$

An updated PSD efficiency study is under progress…

$$N(e^+) = \epsilon N_t \int dE \frac{d\phi}{dE_{\bar{\nu}_e}} \sigma_{IBD}(E, E^+)$$

Differential cross section

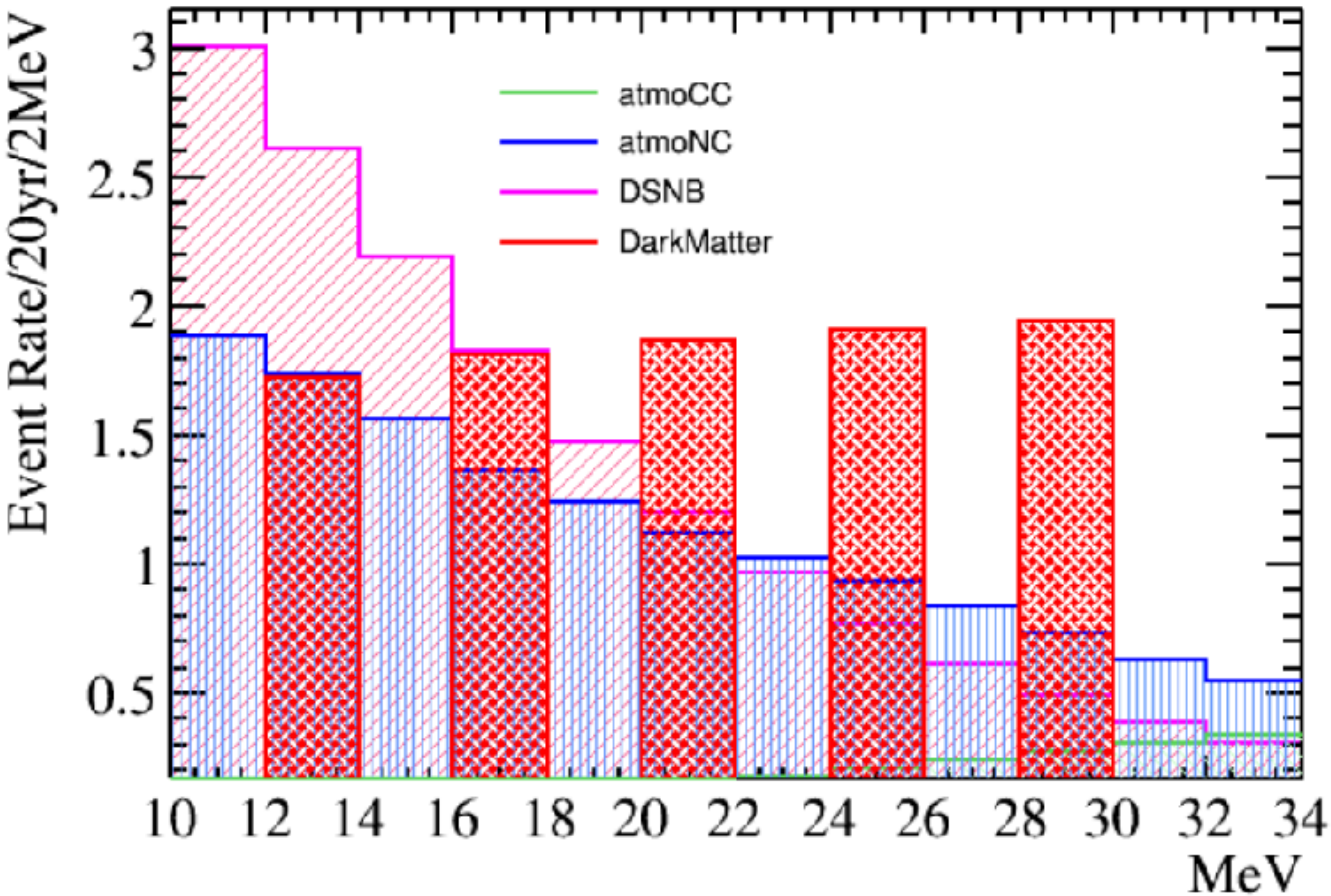
$N_t = 1.2 \times 10^{33}$ for 17 kiloton of fiducial volume



We shall take fiducial DSNB model for further studies

- Detailed DSNB study: Yufeng Li, JUNO Doc. 3213-v1
- Updated Atmospheric NC background study: Jie Cheng, JUNO Doc. 3210-v1

Klaes Mller, Anna M. Suliga, Irene Tamborra, and Peter B. Denton, arXiv: 1804.03157



$$< \sigma v >= 3 \times 10^{-26} cm^3/s$$

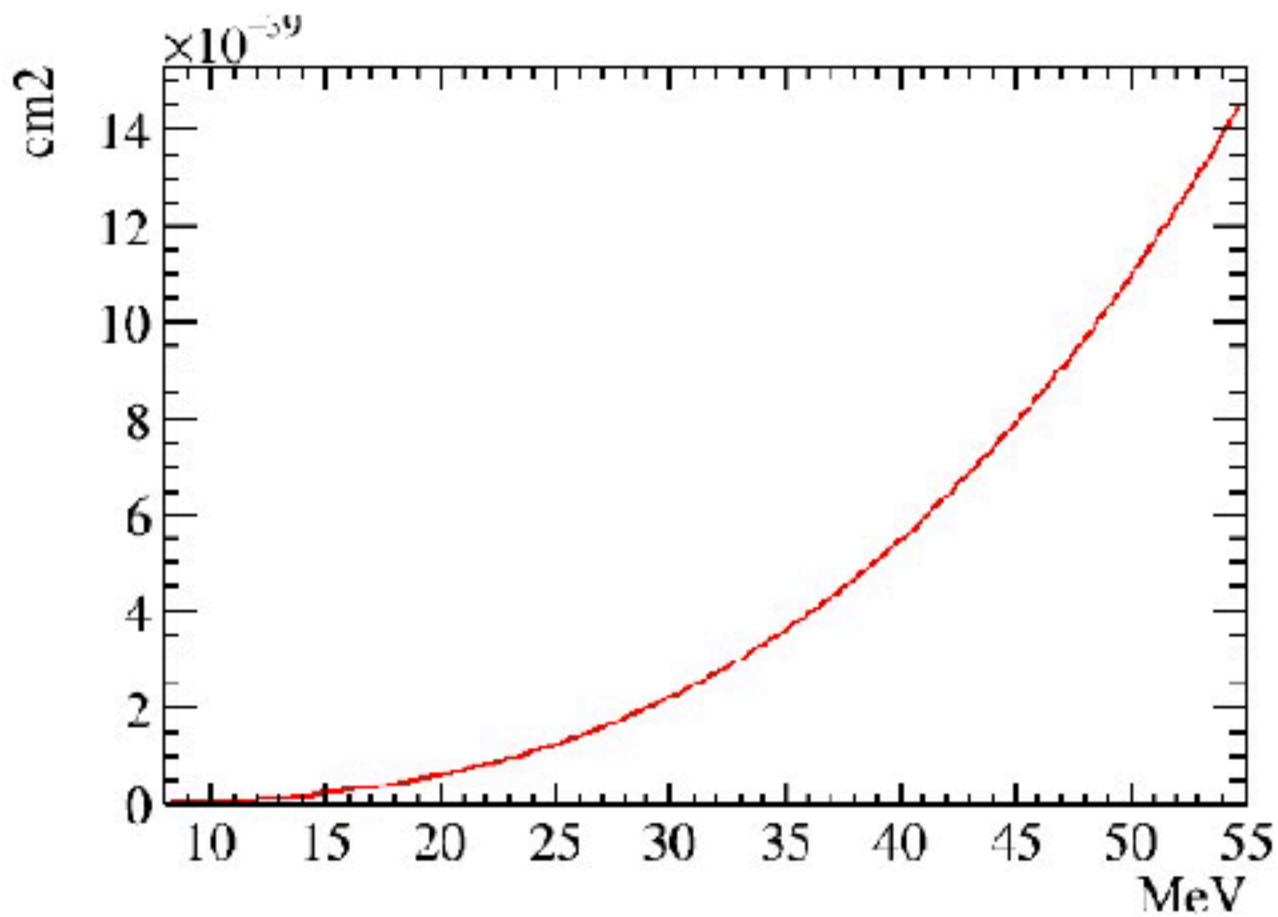
Why does the DM induced neutrino event rate appears independent of DM mass/neutrino energy?

$$\frac{d\phi}{dE_\nu} = \frac{\langle \sigma_A v \rangle}{2} \mathcal{J}_{\text{avg}} \frac{R_{\text{sc}} \rho_0^2}{m_\chi^2} \frac{1}{3} \delta(E_\nu - m_\chi),$$

IBD cross section

- Phys. Rev. D **60**, 053003(1999, P. Vogel and J. F. Beacom)

$$\sigma_{tot}^{(0)} = \sigma_0 \left(f^2 + 3g^2\right) E_e^{(0)} p_e^{(0)}$$
$$= 0.0952 \left(\frac{E_e^{(0)} p_e^{(0)}}{1\ \text{MeV}^2}\right) \times 10^{-42}\ \text{cm}^2$$



Search by KamLand:

$$\langle \sigma_A v \rangle < (1\text{–}3) \times 10^{-24}\,\mathrm{cm}^3\mathrm{s}^{-1}$$

for $8.3\,\mathrm{MeV} < m_\chi < 31.8\,\mathrm{MeV}$

JUNO should be able to do better!

Summary

- We have summarized the DM physics in JUNO proposed in the yellowbook.
- We further propose the detection of MeV mass neutrinos resulting from the DM annihilation in the galactic halo.
- The backgrounds for the above search are discussed. Previous studies on these background issues by JUNO collaborators are mentioned.
- We shall begin to perform more serious studies.