Searching for Diffuse Supernova Neutrino Background

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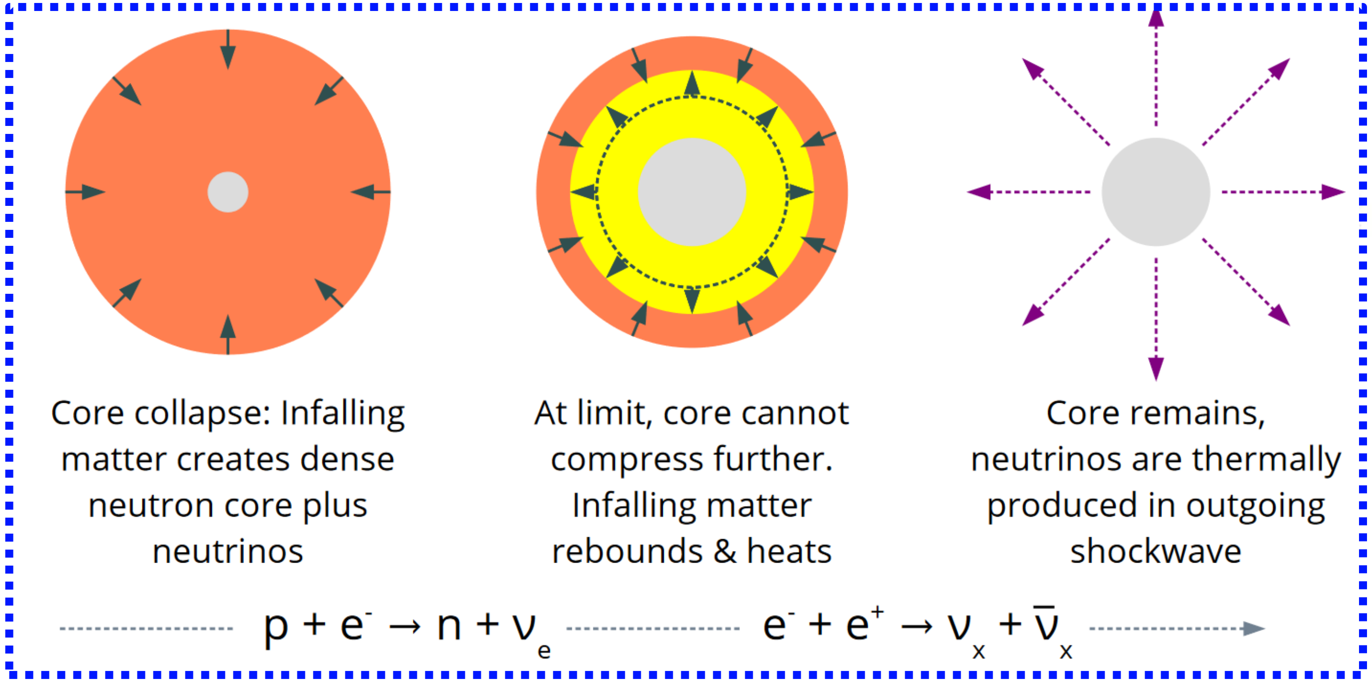
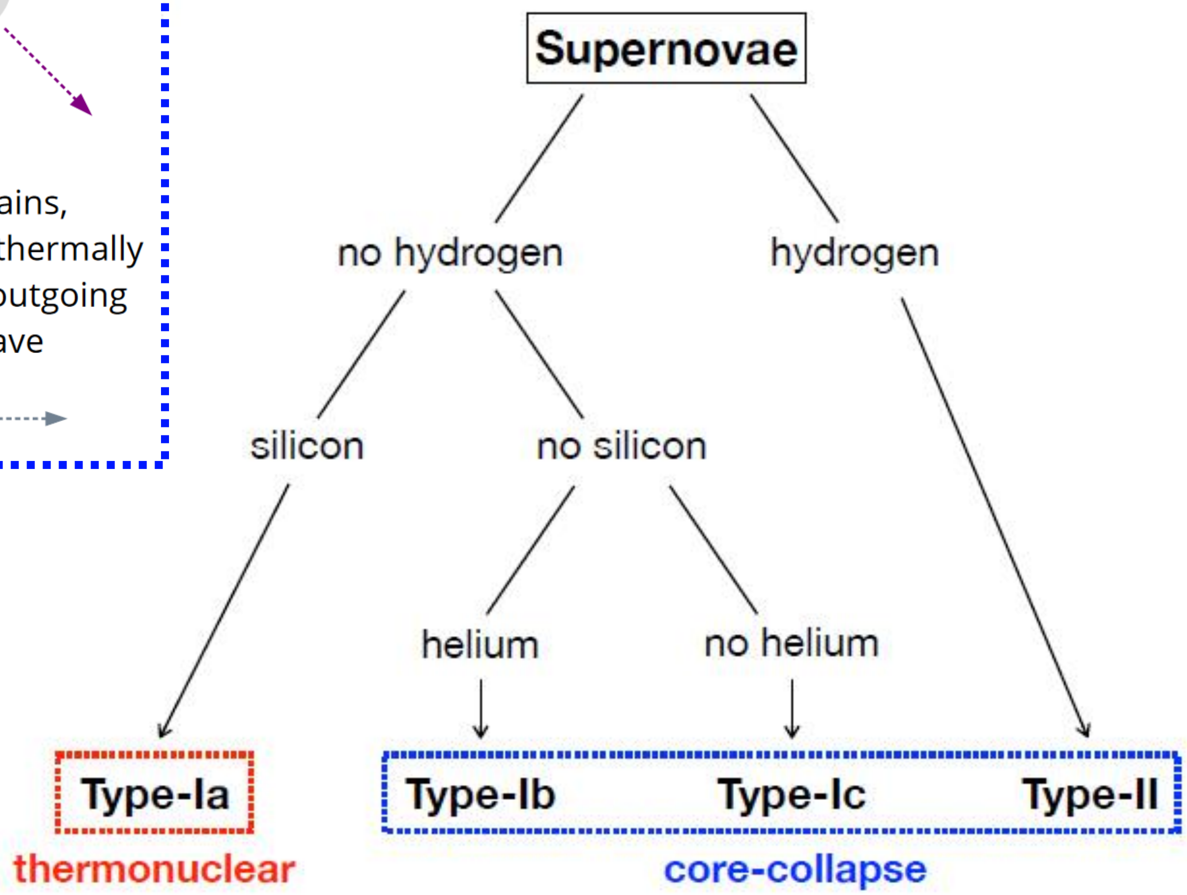
@CoSSURF, Rapid City

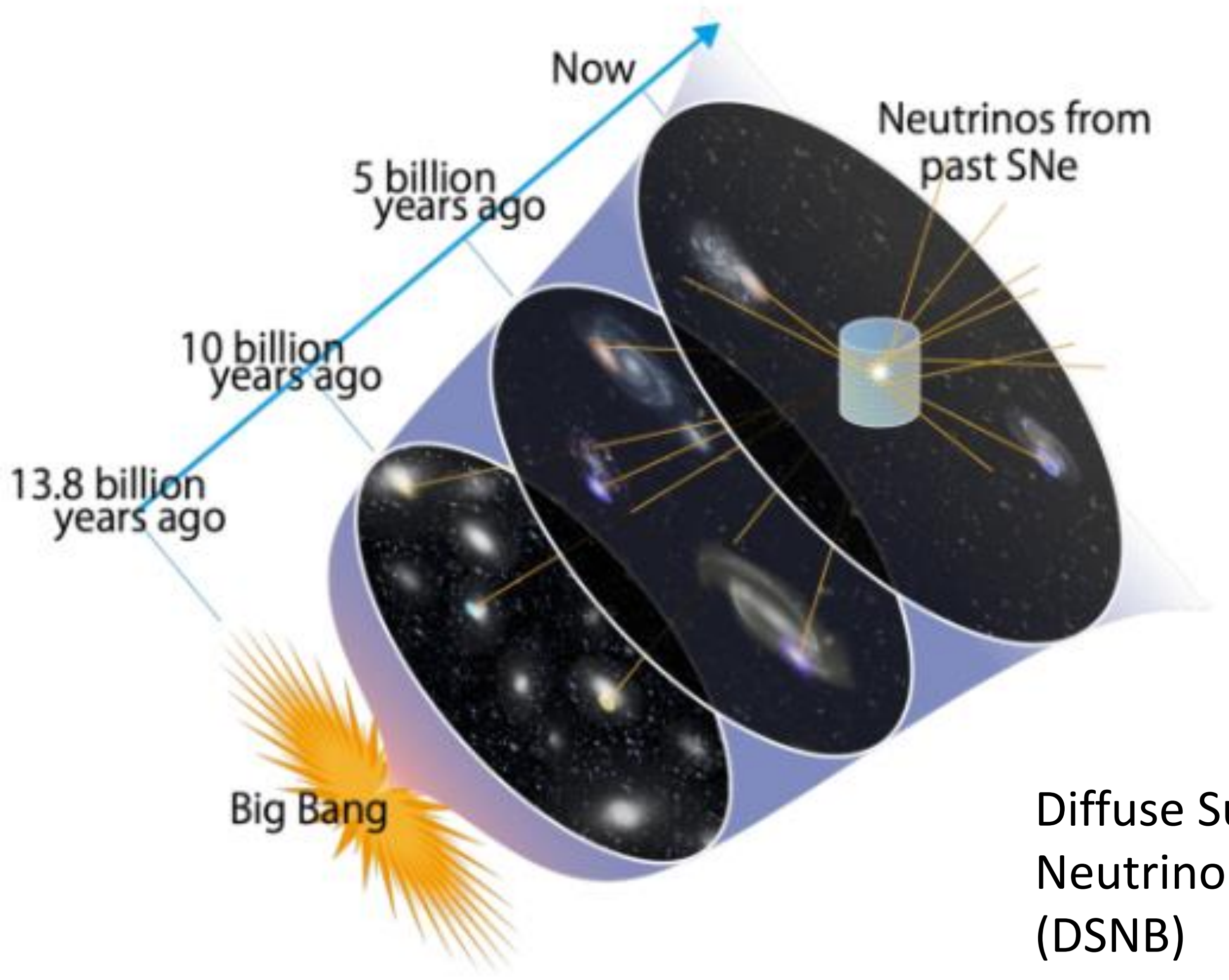
Core Collapse Supernova



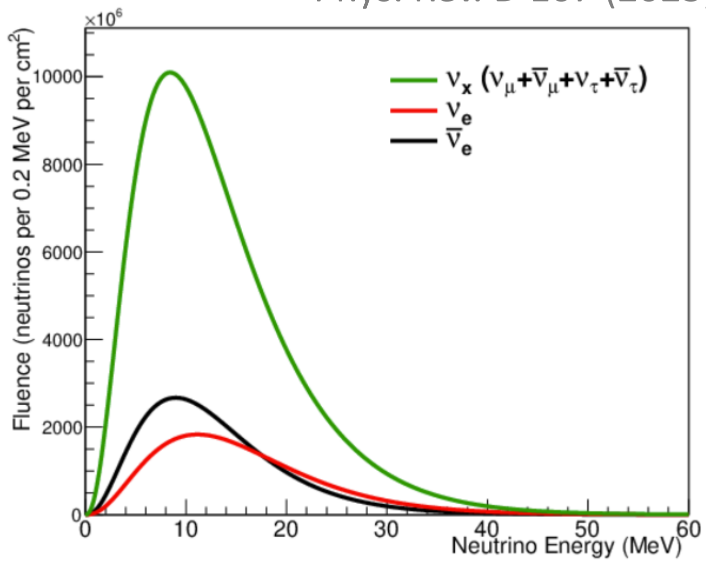


Trace Back in Time

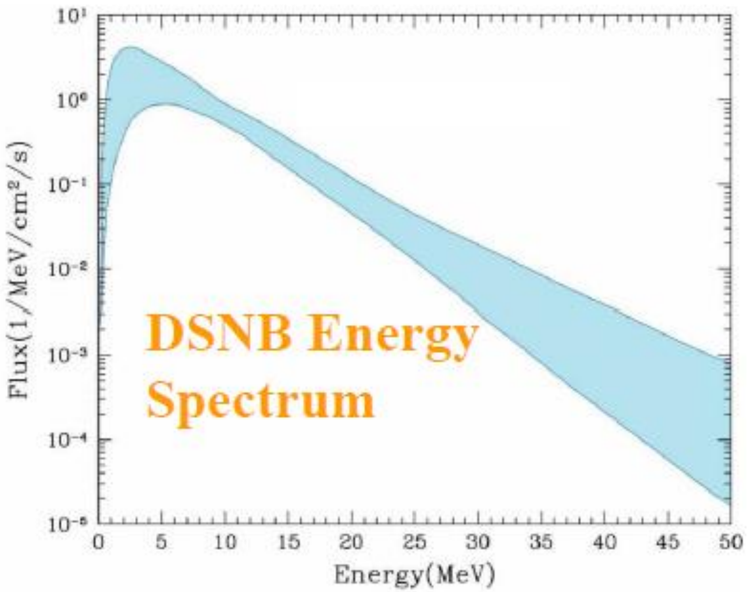
Phys. Rev. D 107 (2023) 112012



Diffuse Supernova Neutrino Background (DSNB)



Redshift + Integral



What can we learn from DSNB?

- **Spectrum and flux**
  - Average temperature and luminosity
  - Typical supernovae dynamics

- **Rate of core-collapse supernovae**

- **Universe's history and evolution**

Line-of-sight integral in redshift

→ *New SNe & particle physics effects!*
Neutrino emission spectrum

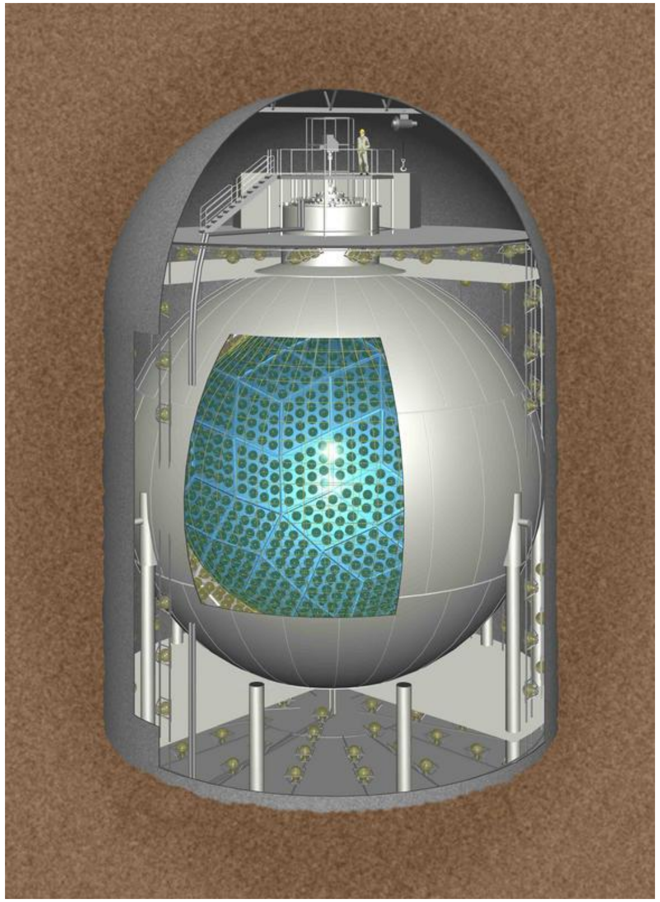
$$\frac{d\Phi(E_\nu)}{dE_\nu} = \int_0^{z_{\max}} R_{\mathrm{SN}}(z) \frac{dN[E(1+z)]}{dE} (1+z) \left| \frac{dt}{dz} \right| dz$$

DSNB Flux

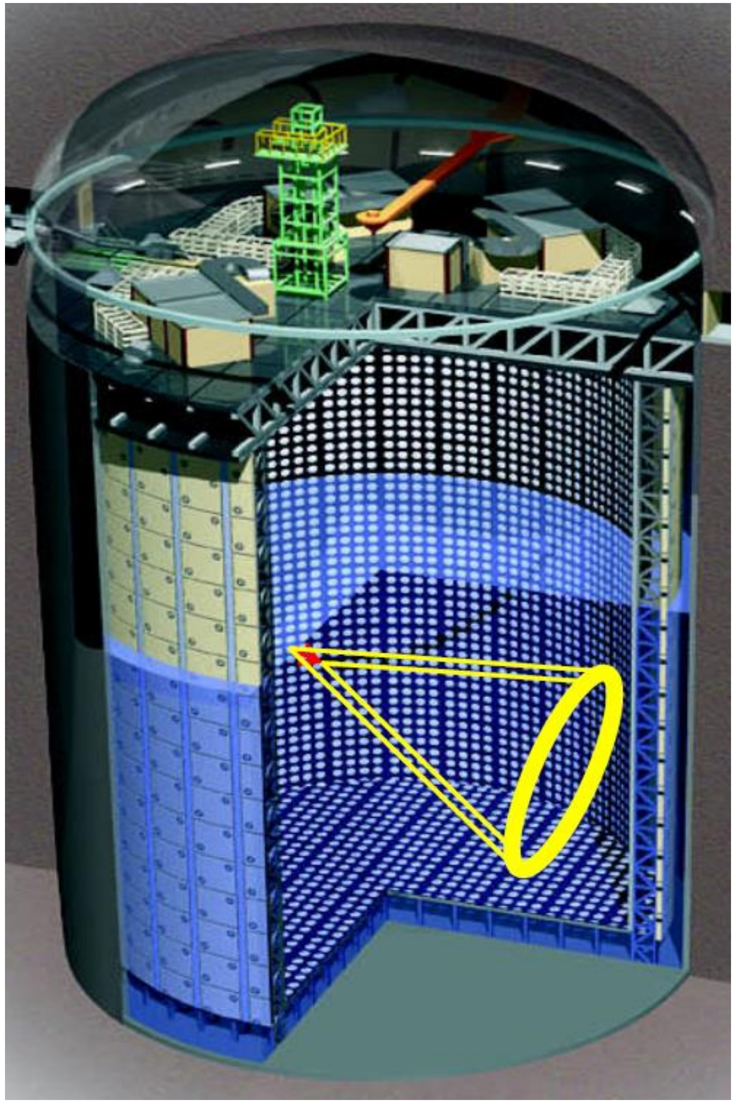
CC SNe rate
→ *Cosmology and star formation!*

(ΛCDM) Cosmology
→ *Cosmological effects!*

DSNB Detection

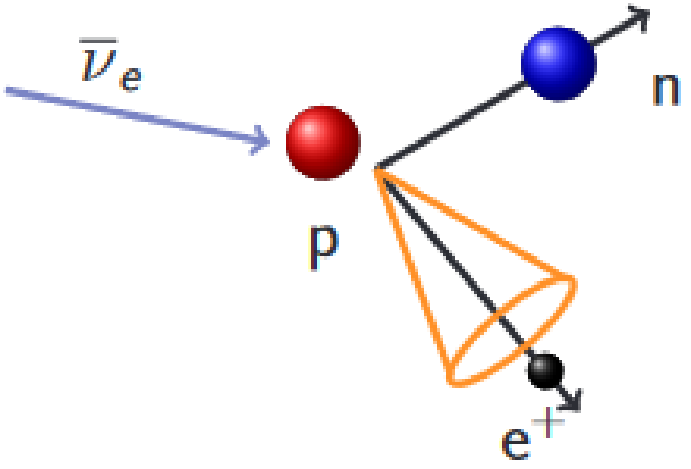


KamLAND
1 kton LS



Super-Kamiokande
22.5 kton water

DSNB in Water



- Inverse Beta Decay

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

Signal: IBD positron Also called the primary event

(+ neutron capture gamma).

- Neutron Capture

$$n + p \rightarrow D + \gamma$$

□ H Capture $\tau = 200\ \mu s$ $E_\gamma = 2.2$ MeV

DSNB Backgrounds

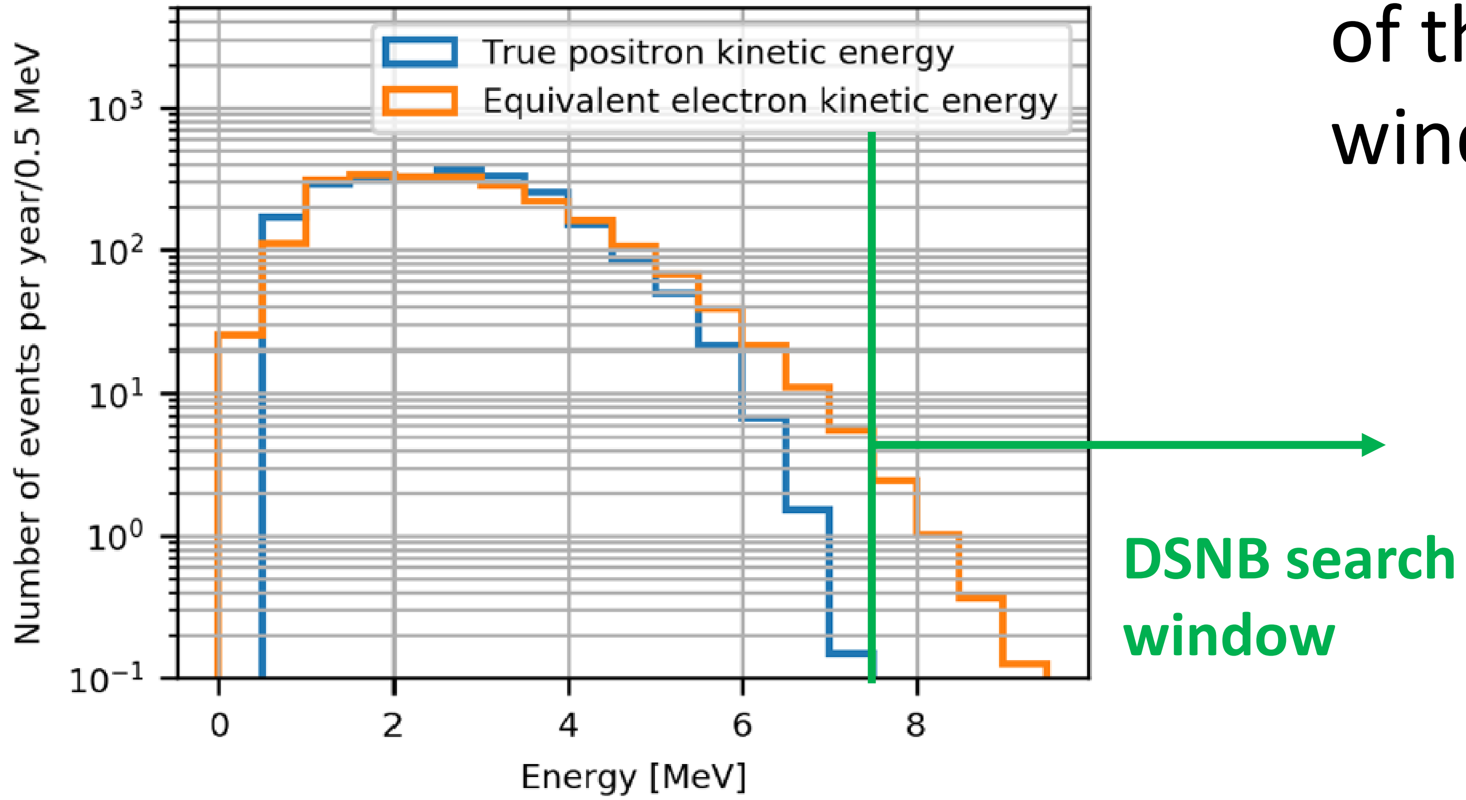
DSN B search is a **rare** signal search:
~ a few events / year / 20 kton

Backgrounds:

- Reactor neutrinos
- Spallation backgrounds
- Atmospheric neutrinos
- Accidental coincidence

DSNB Backgrounds: Reactor Neutrinos

Phys.Rev.D 104 (2021) 12, 122002



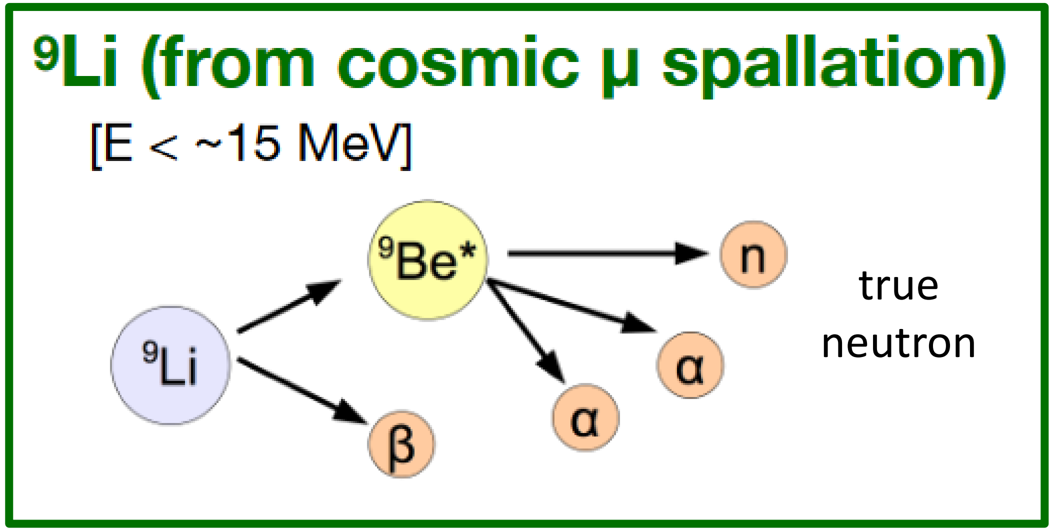
- Irreducible backgrounds
- Set the energy threshold of the DSNB search window

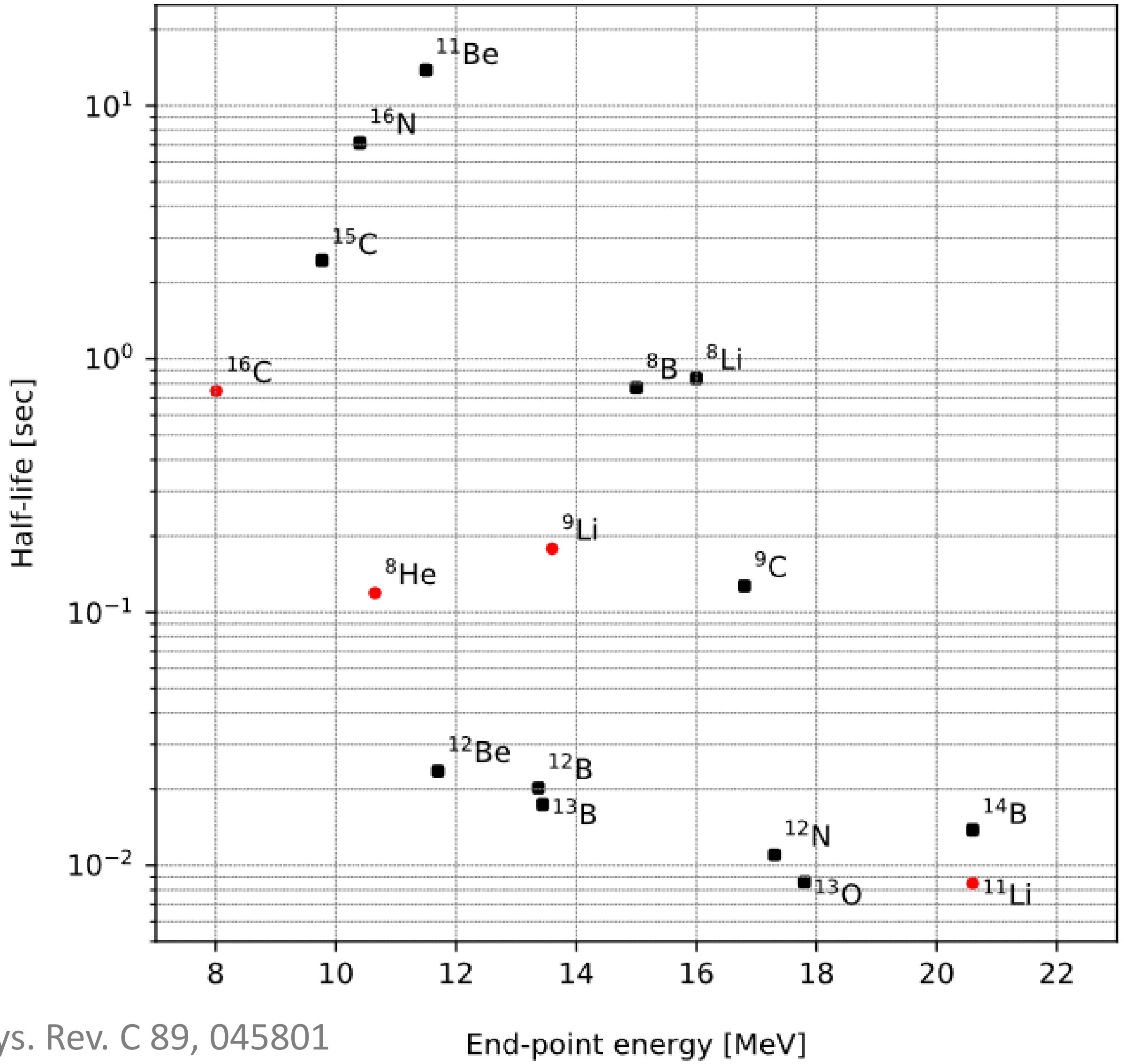
DSNB Backgrounds: Spallation

- Cosmic-ray muon rate is ~2 Hz at SK.
- Some muons break oxygen nuclei and produce radioactive isotopes.
- Some isotopes decay with neutron emission.

$^{8}\mathrm{He}: 0.23 \times 10^{-7} \mu^{-1} \mathrm{g}^{-1} \mathrm{cm}^{2}$

$\mathbf{^{9}Li: 1.9 \times 10^{-7} \mu^{-1} g^{-1} cm^{2}}$



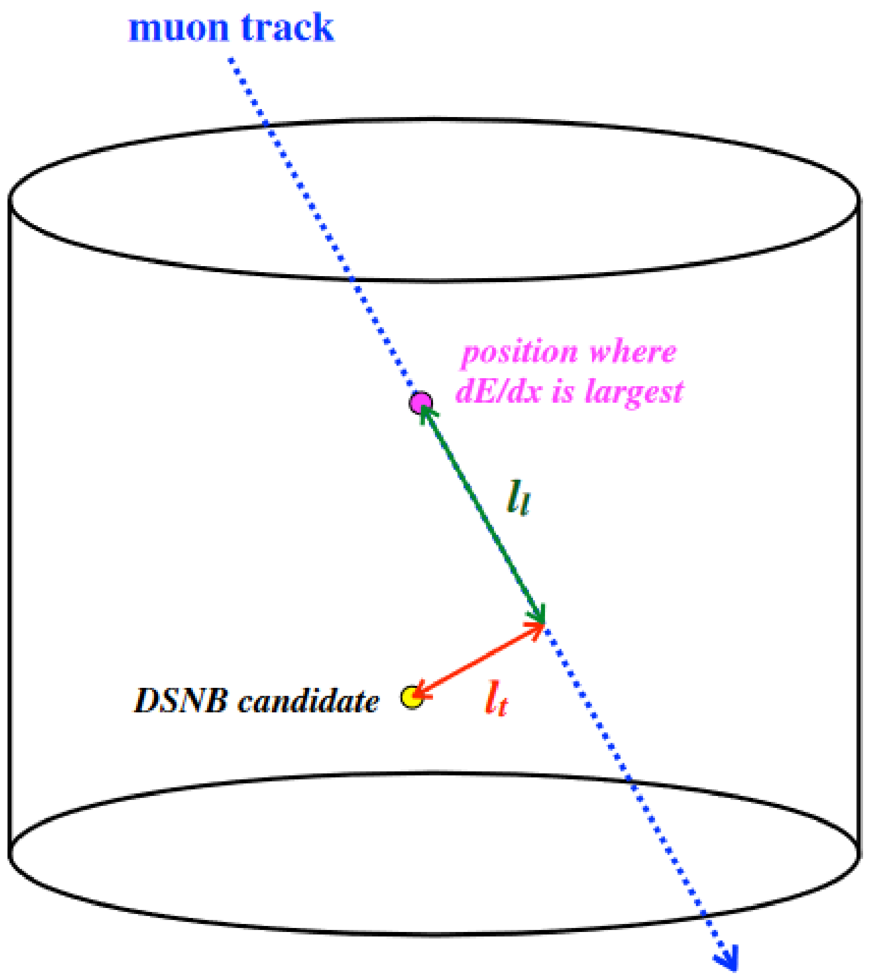


Phys. Rev. C 89, 045801

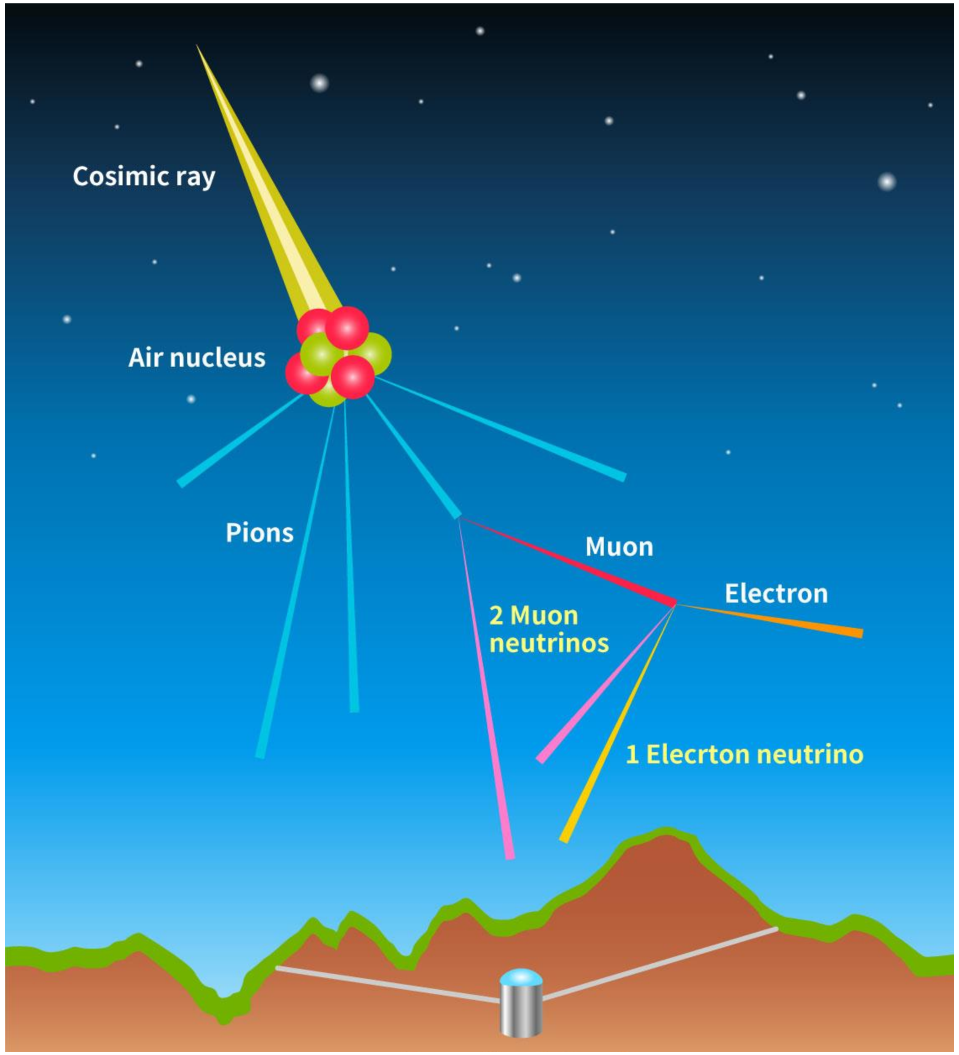
Spallation Cut

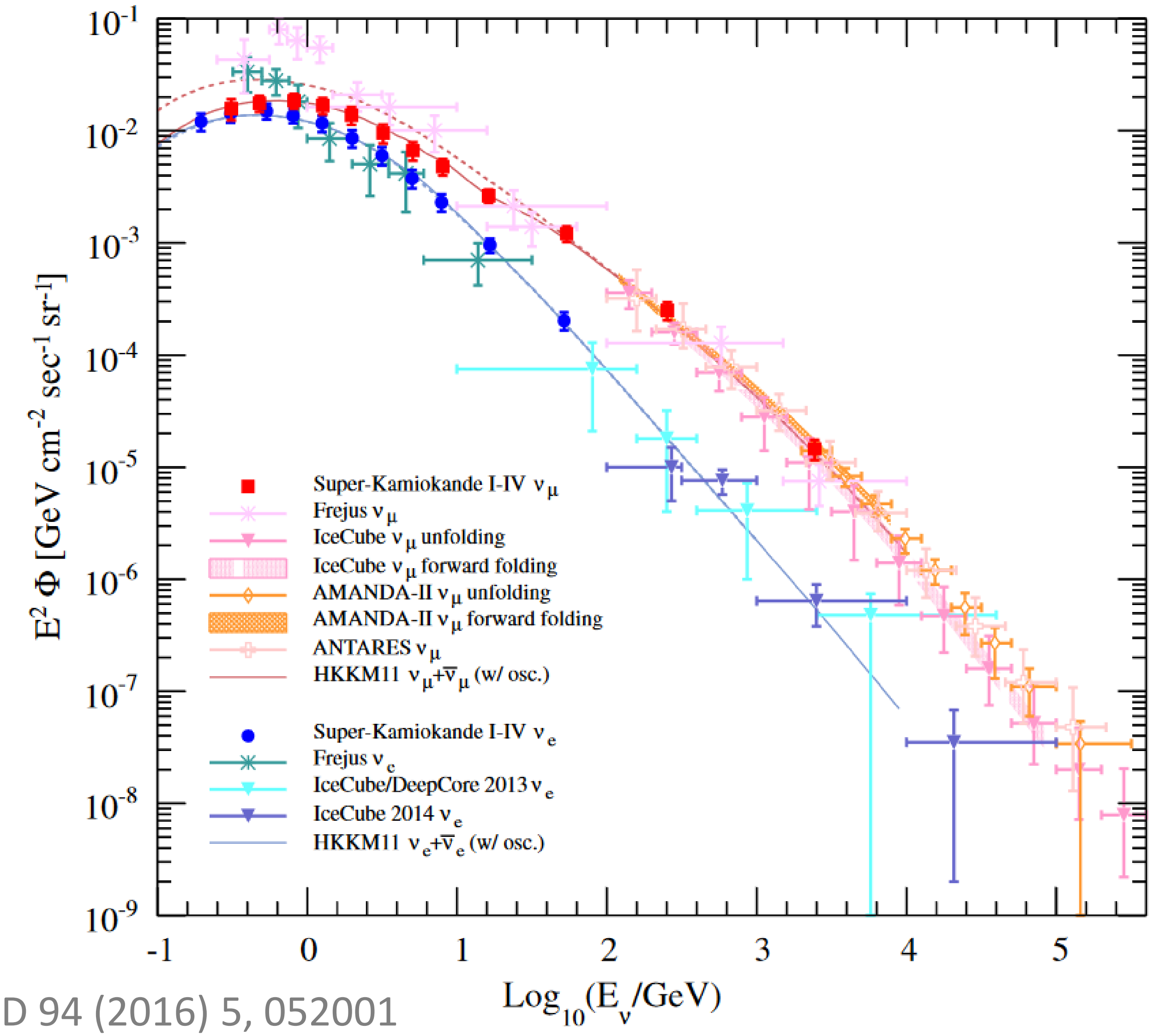
- Events close to muon track in time, transverse distance (l_t), and longitudinal distance (l_l) are more likely to be spallation products.
- Large energy depositing muons are more likely to produce spallation.
- Clustered low energy events (in time and position) are more likely to be from the same spallation.

These efforts reject >95% spallation background.



DSNB Backgrounds: Atmospheric Neutrinos



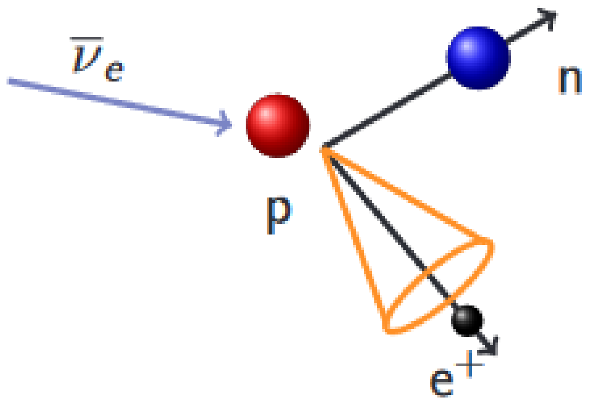


Phys.Rev.D 94 (2016) 5, 052001

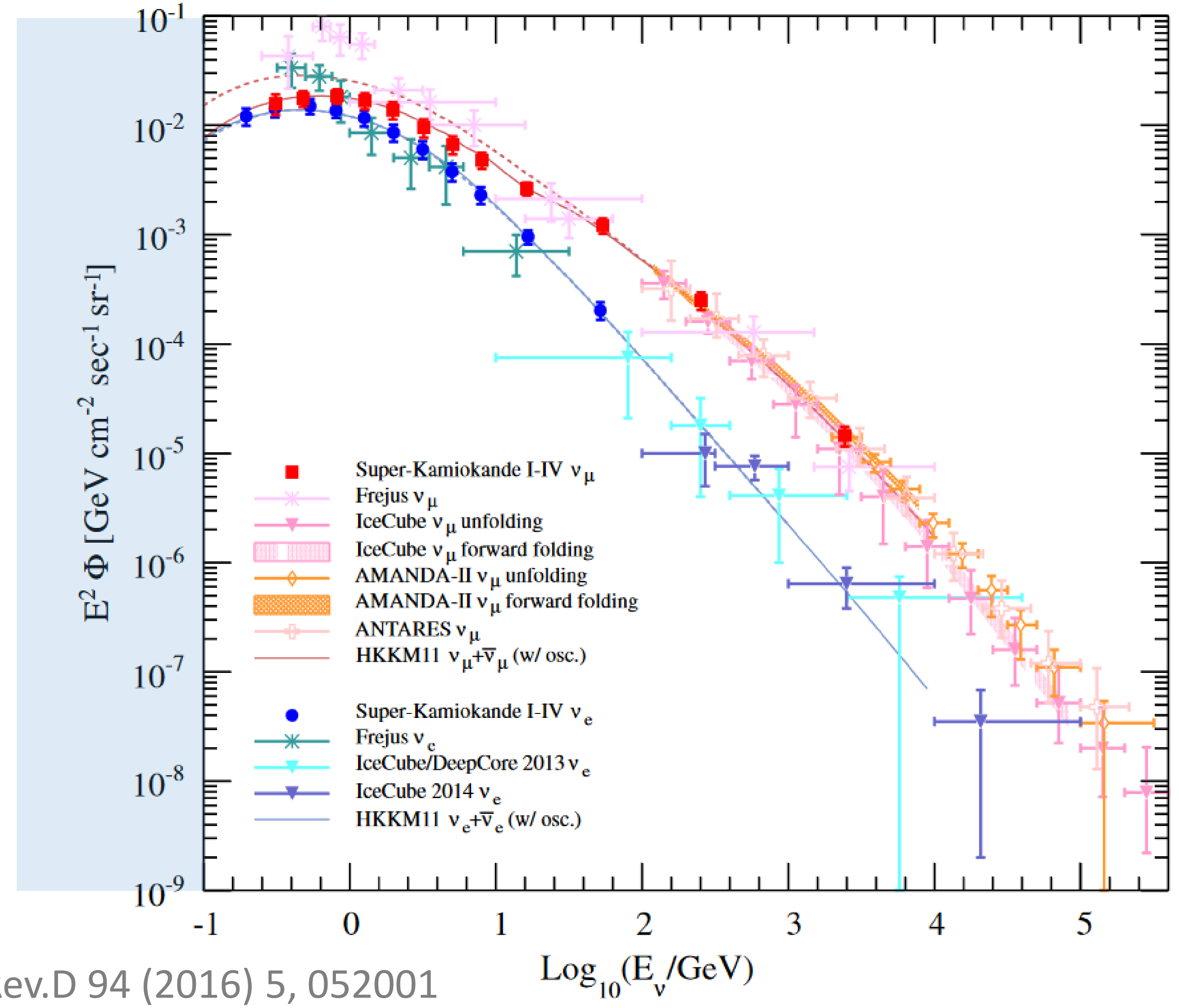
DSNB Backgrounds: ν_e Charged Current

Flux unconstrained

ν_e CC [E > ~20 MeV]



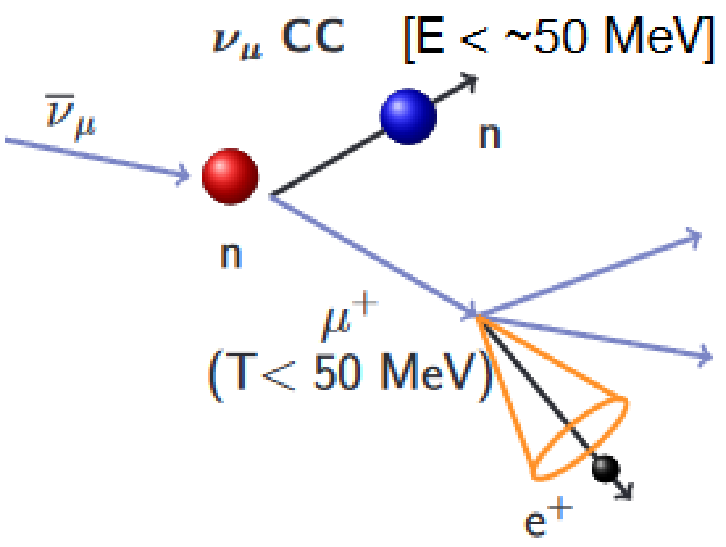
- Irreducible IBD



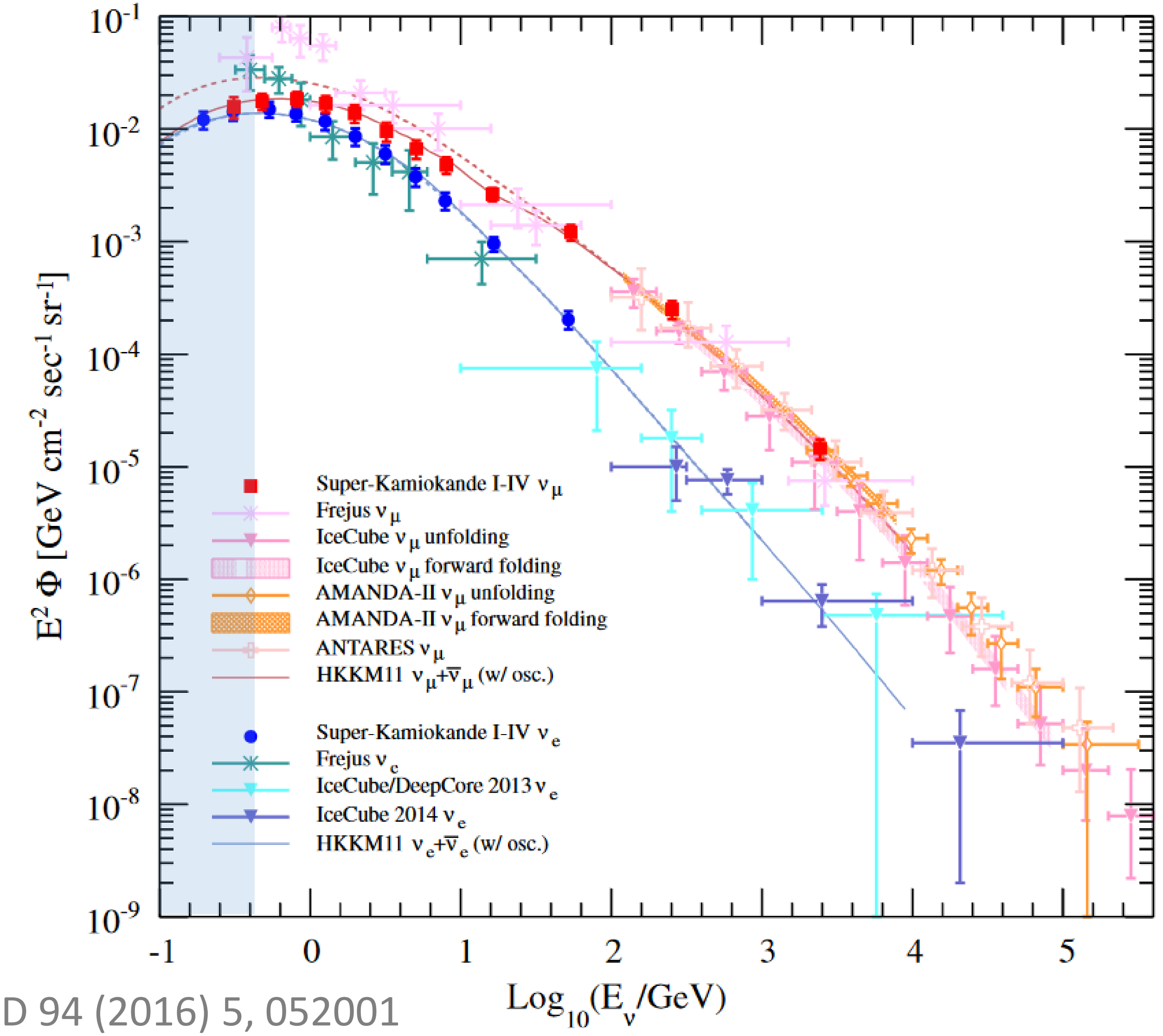
Phys.Rev.D 94 (2016) 5, 052001

DSNB Backgrounds: ν_μ Charged Current

Analysis ongoing



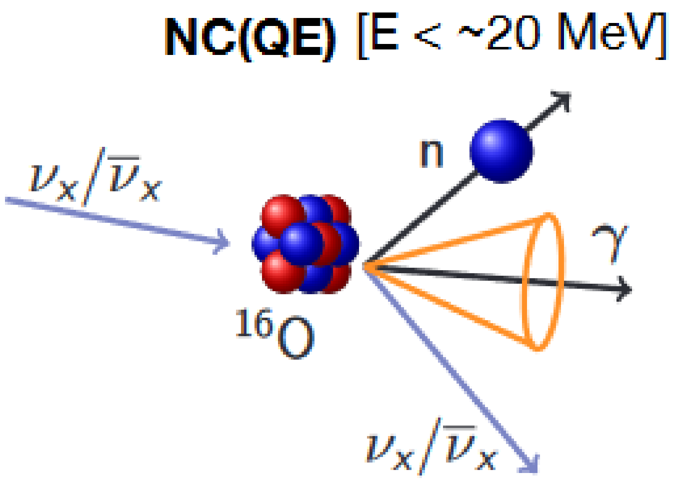
- Mis-identified muon;
- Decay electron from invisible muon



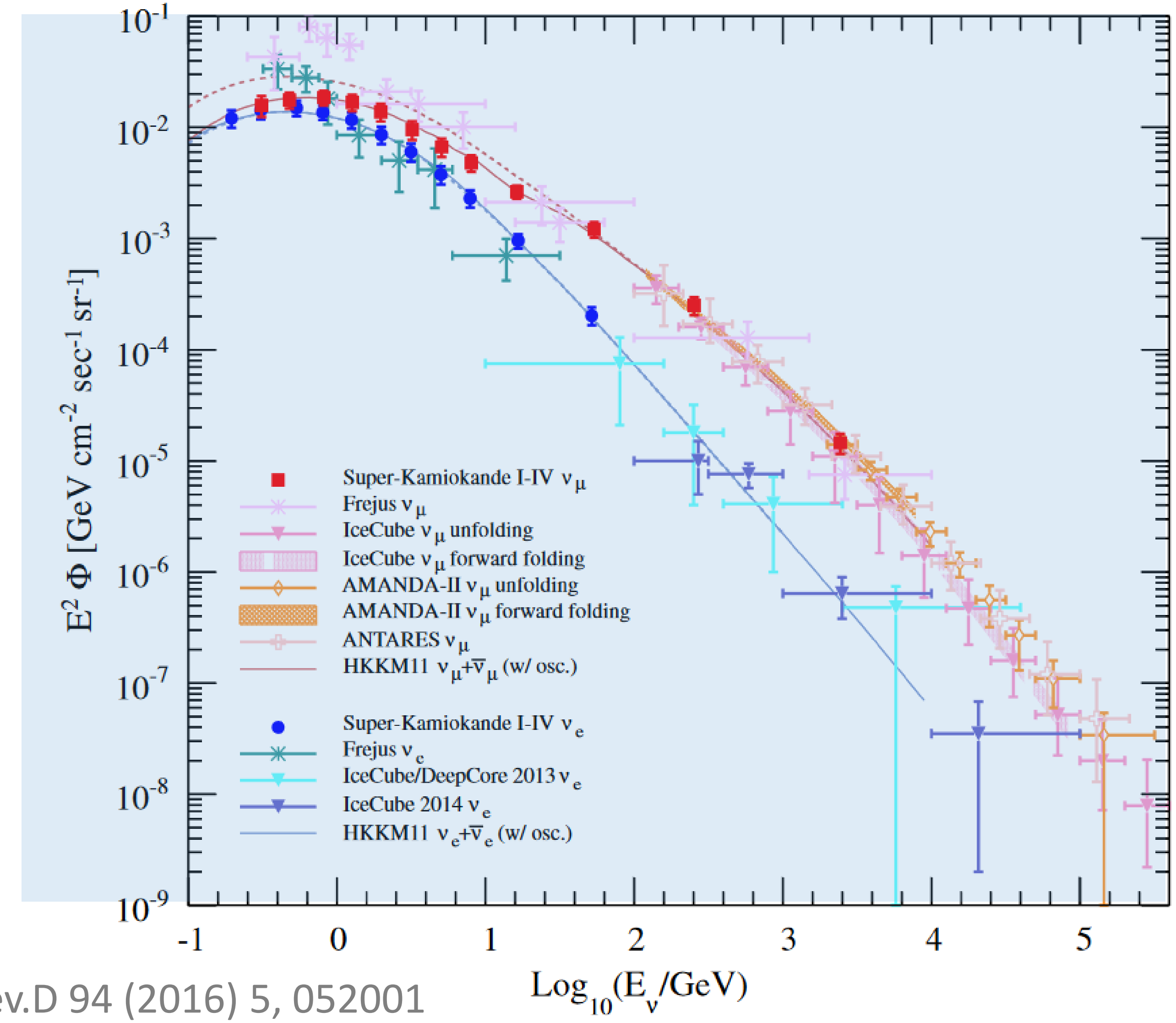
Phys.Rev.D 94 (2016) 5, 052001

DSNB Backgrounds: Atmospheric Neutrinos

L. Wan et. al, Phys. Rev. D 99, 032005 (2019)



- Gamma mis-identified as electron



Phys.Rev.D 94 (2016) 5, 052001

DSNB Backgrounds: Accidental Coincidence

Accidental coincidence = an electron-like event + a fake neutron

Sources of the electron-like event include:

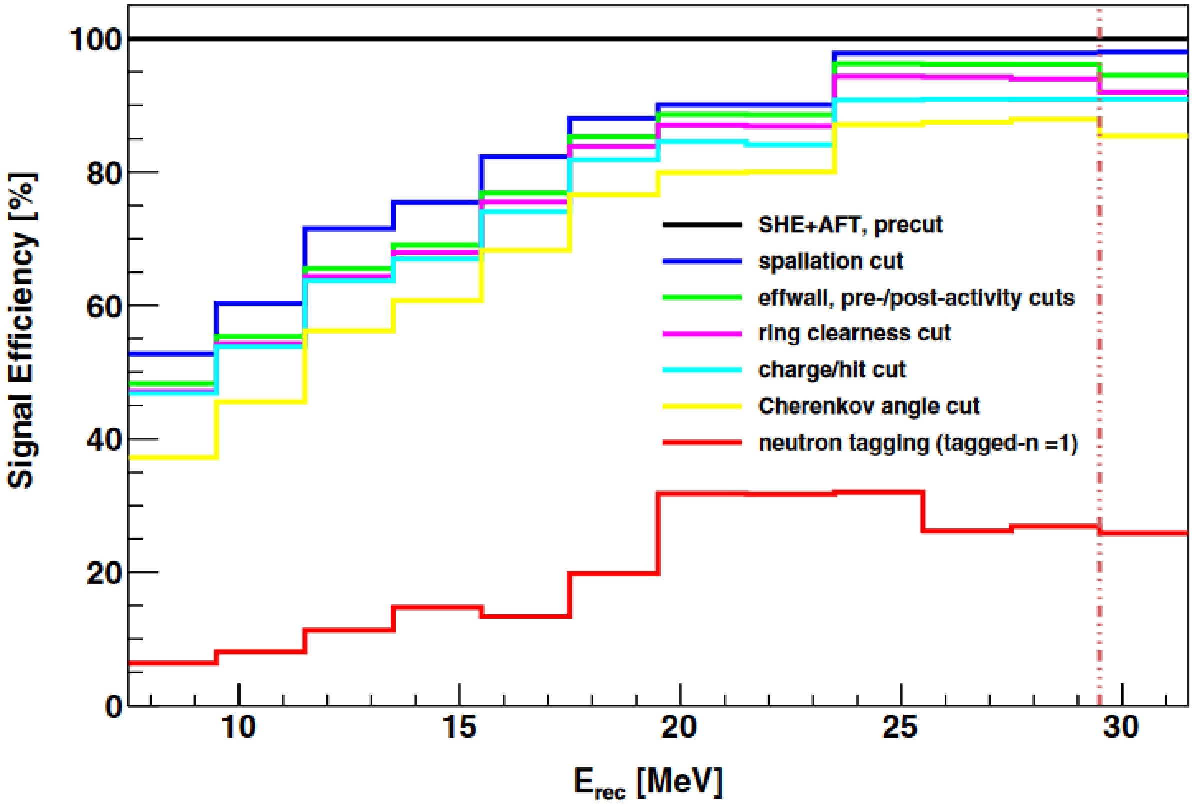
- All DSNB backgrounds
- Spallation products w/o neutron
- Solar neutrinos

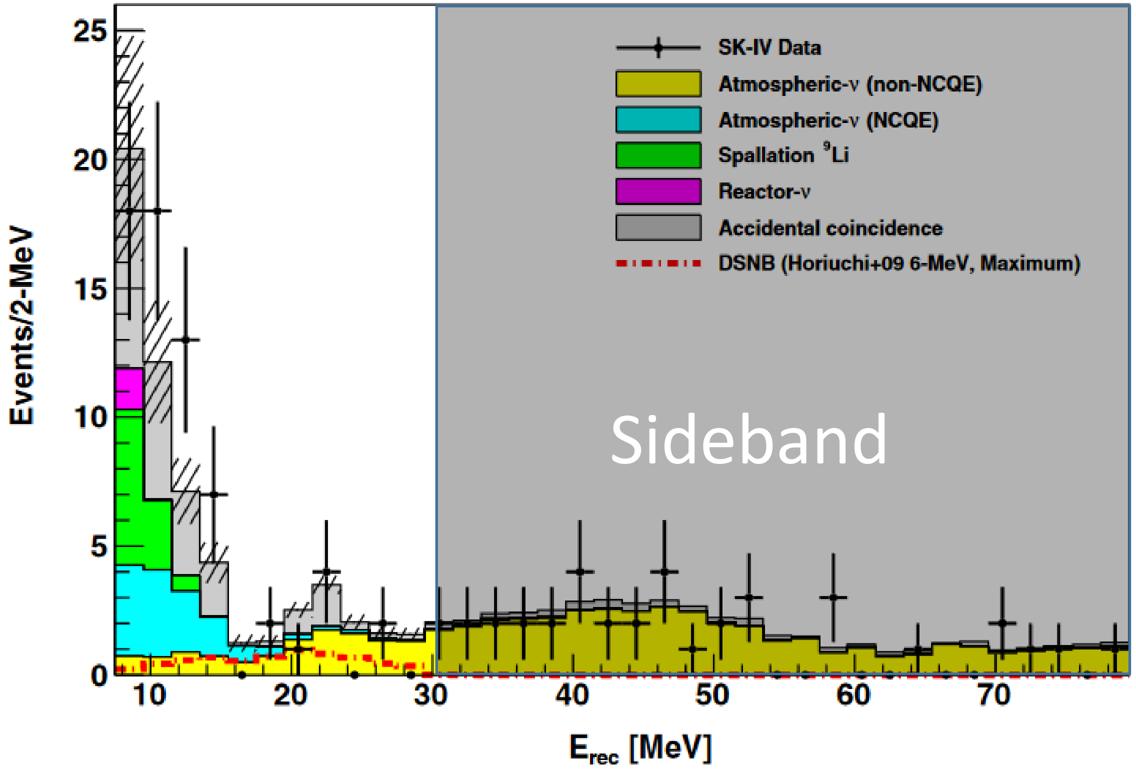
Fake neutrons are formed by:

- PMT dark hits
- Radioactivity
- …

Estimated from dummy trigger data

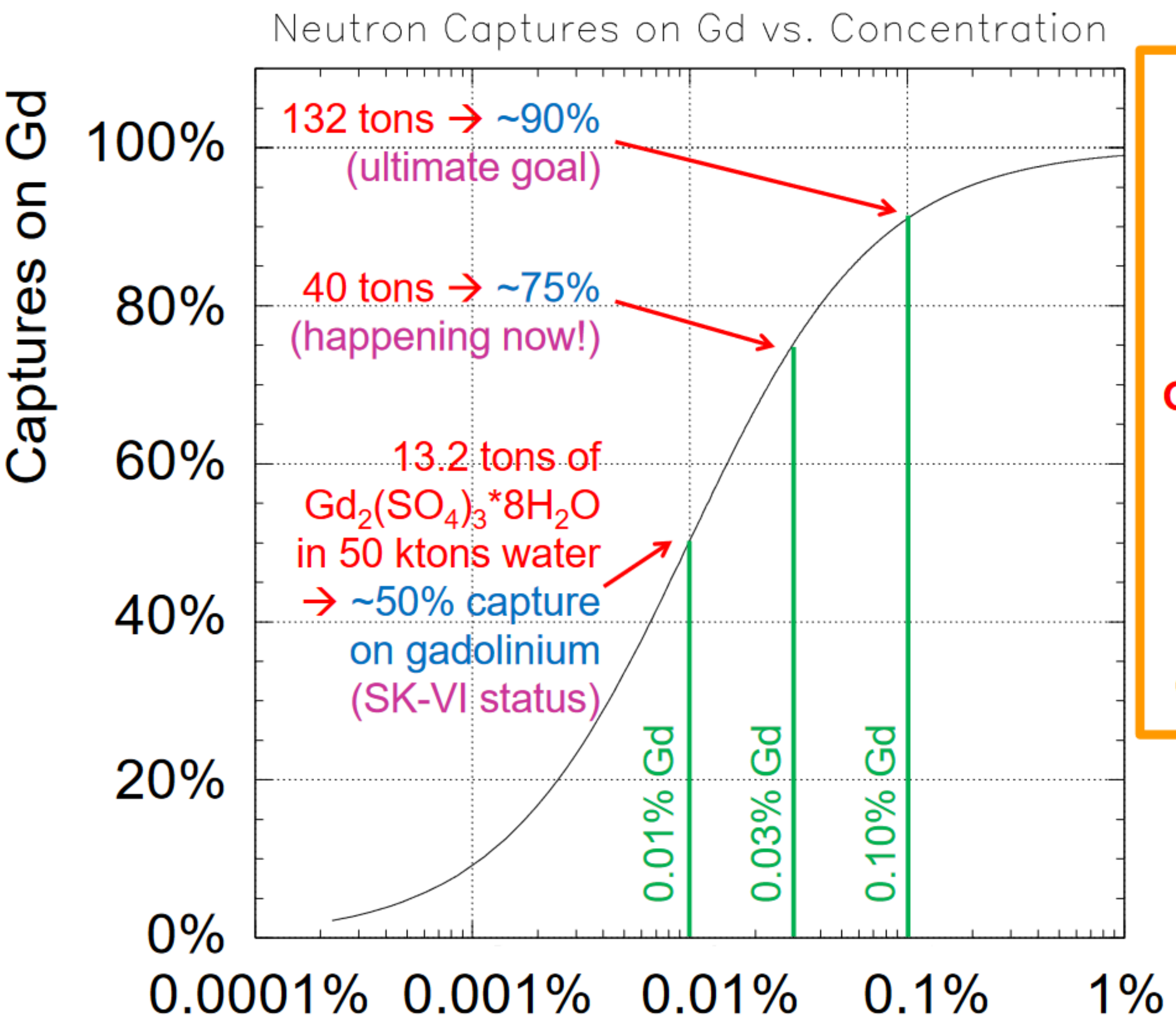
DSNB Final Sample w/ Neutrons and Efficiency





Phys.Rev.D 104 (2021) 12, 122002

SK-Gd



Thermal neutron capture cross section (barns)

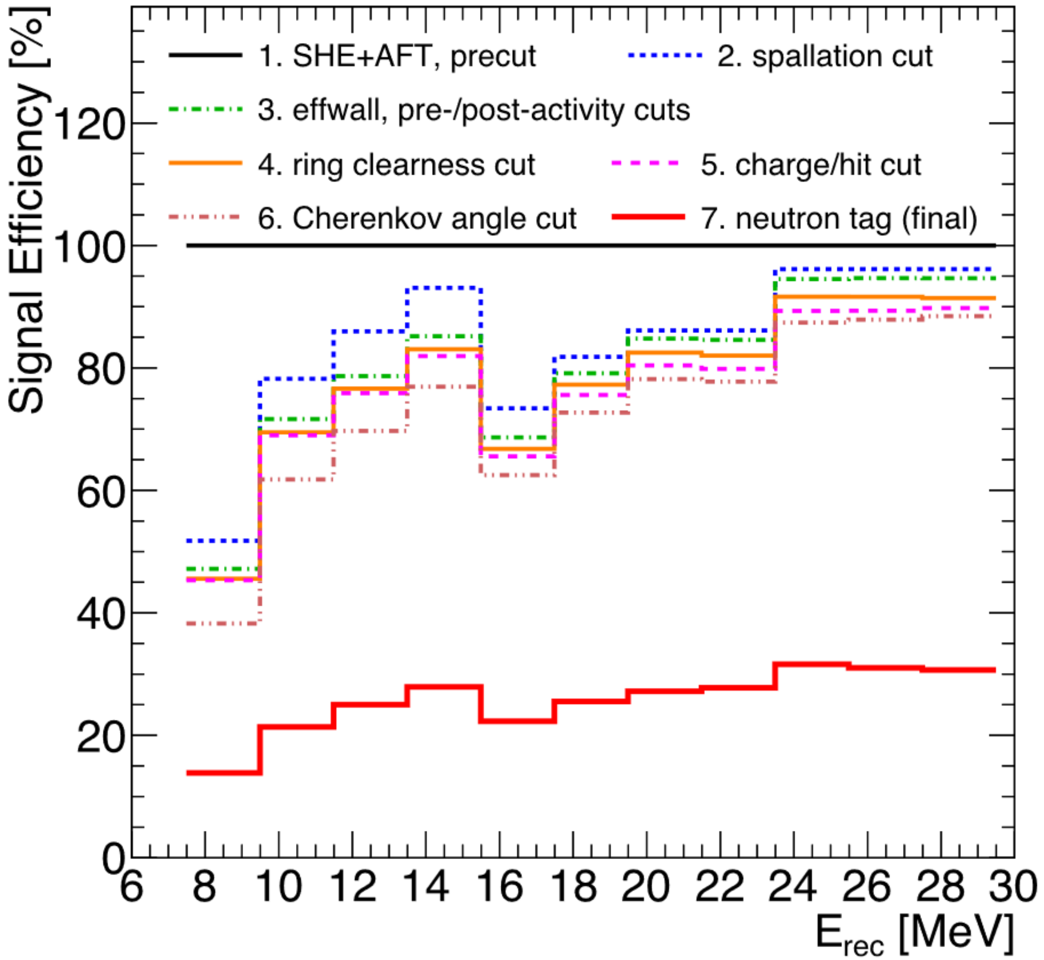
Gd = 49700

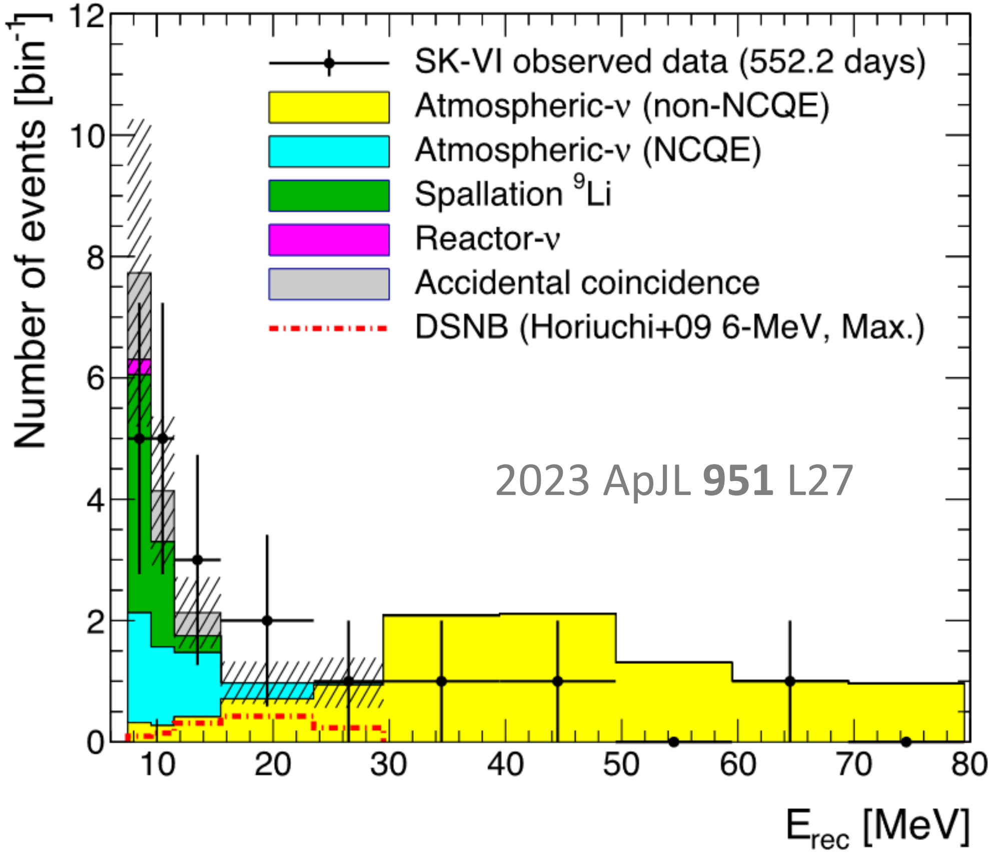
S = 0.53

H = 0.33

O = 0.0002

SK-Gd





Non-NCQE: n=0,1,2…

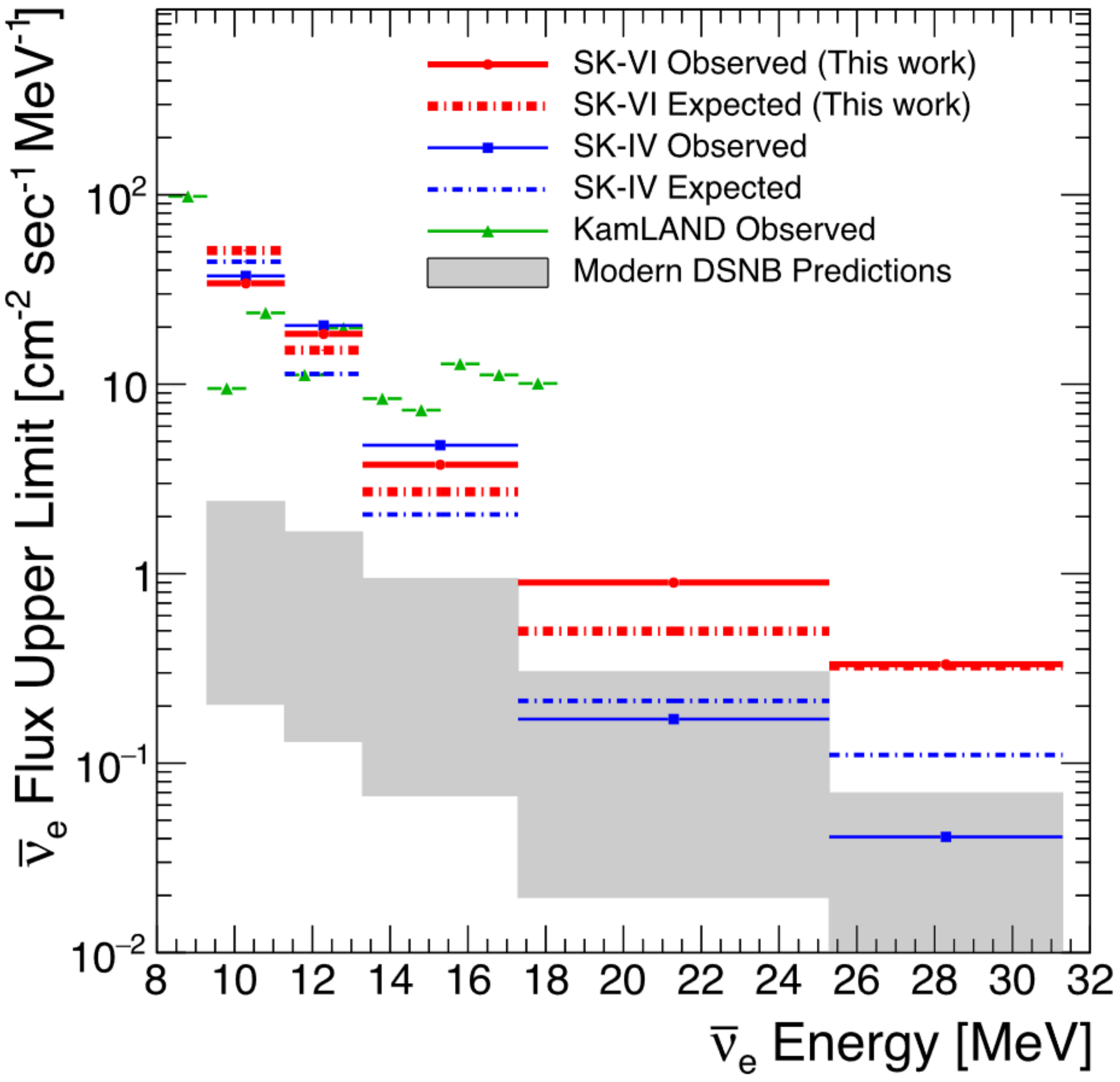
NCQE: n=0,1,2…

Accidental: n=0

DSNB Limit

SK-VI: 22.5 kton x 552 days

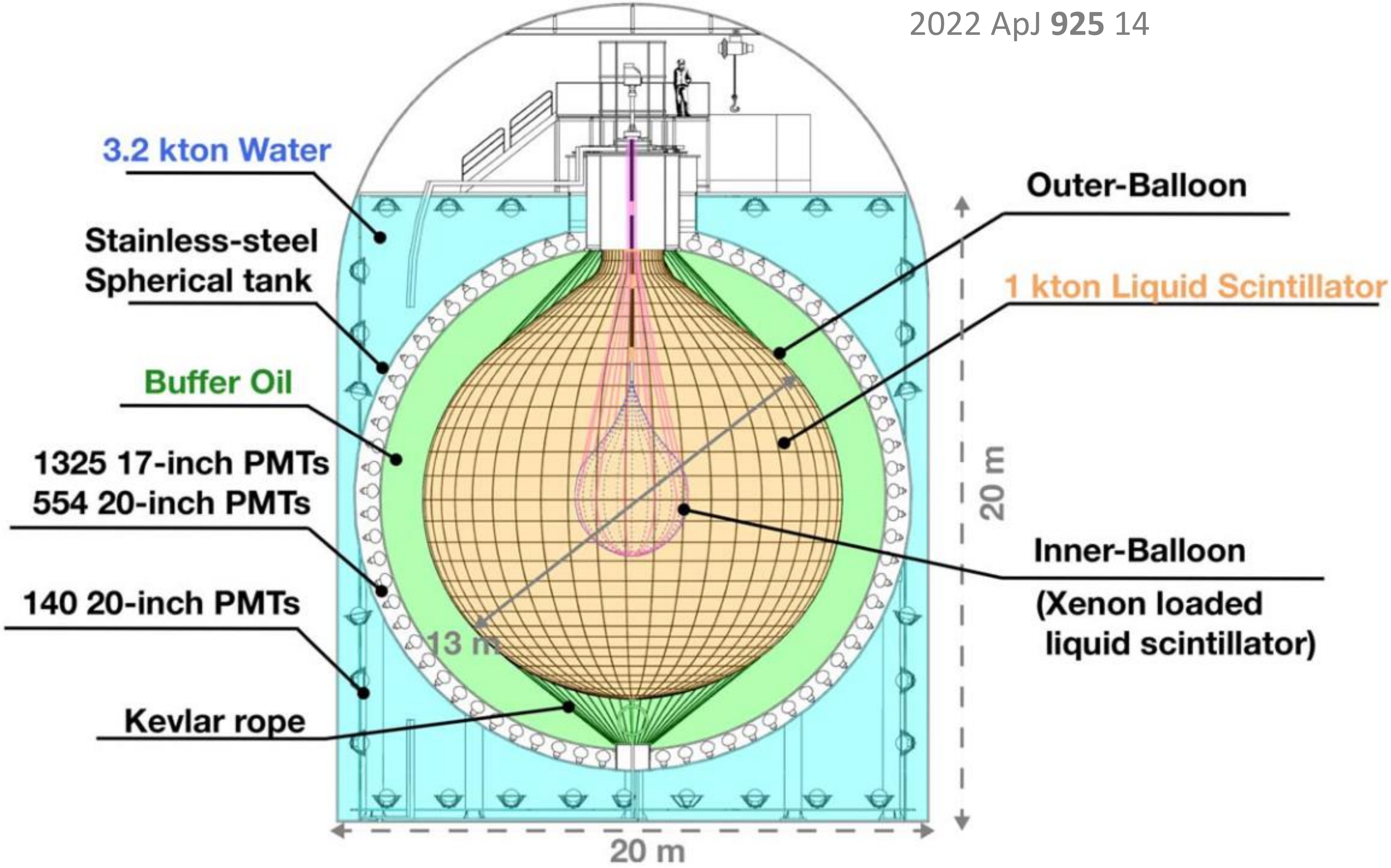
SK-IV: 22.5 kton x 2970 days



2023 ApJL **951** L27

KamLAND(-Zen)

2022 ApJ **925** 14

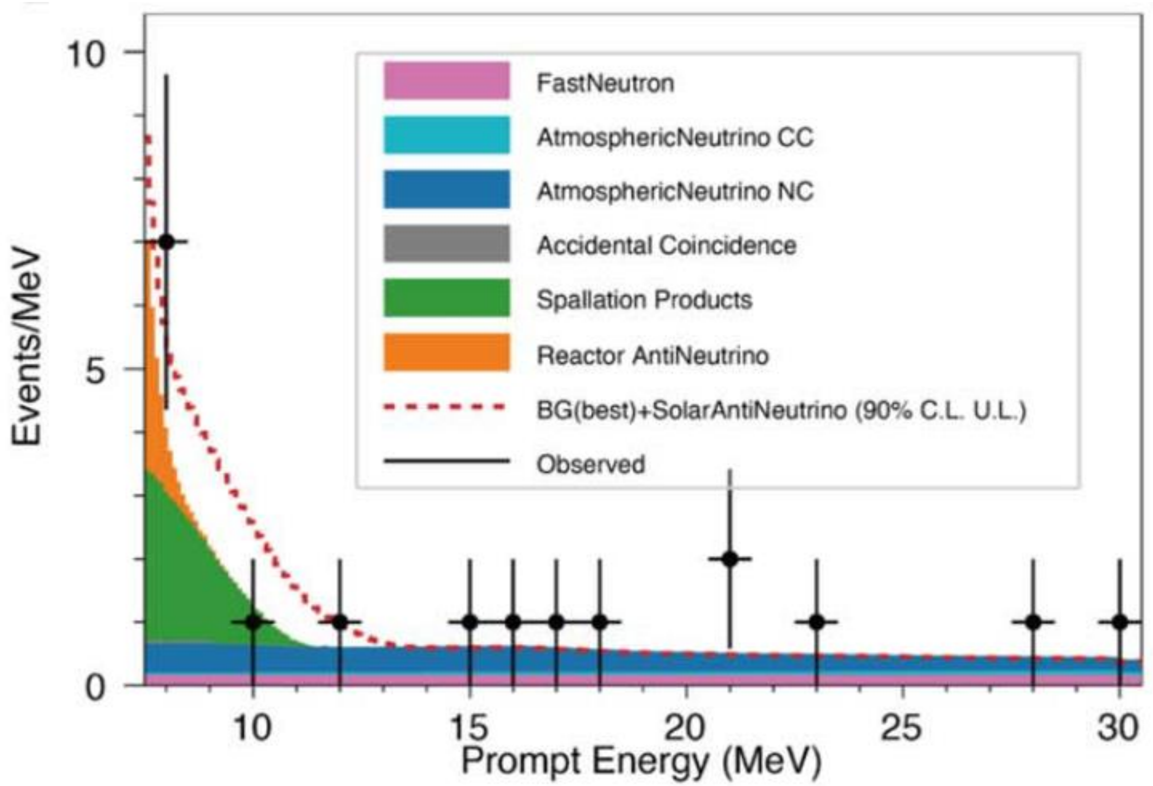


KamLAND

2022 ApJ **925** 14

- Fast neutron from n scatter + n capture
- Atmospheric CC: subdominant
- Atmospheric NC: additional n scatter
- Spallation & Reactor: similar to SK

Efficiency: 92% (73%)

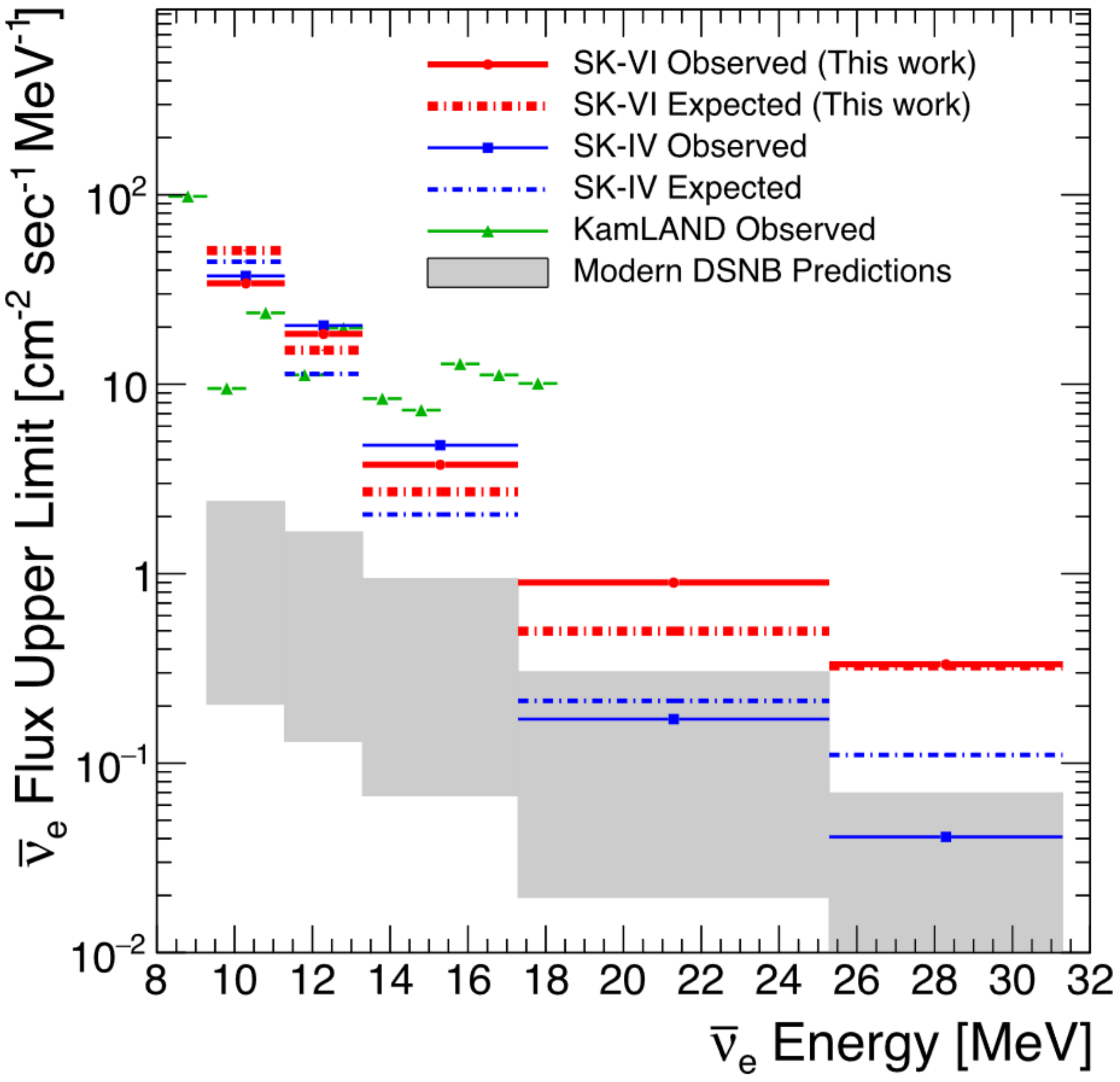


DSNB Limit

SK-VI: 22.5 kton x 552 days

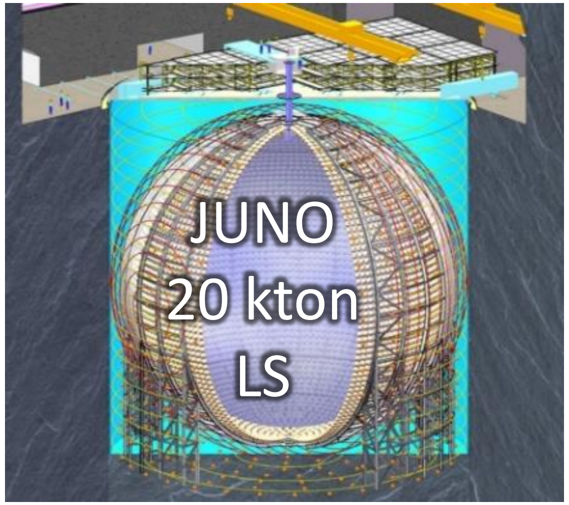
SK-IV: 22.5 kton x 2970 days

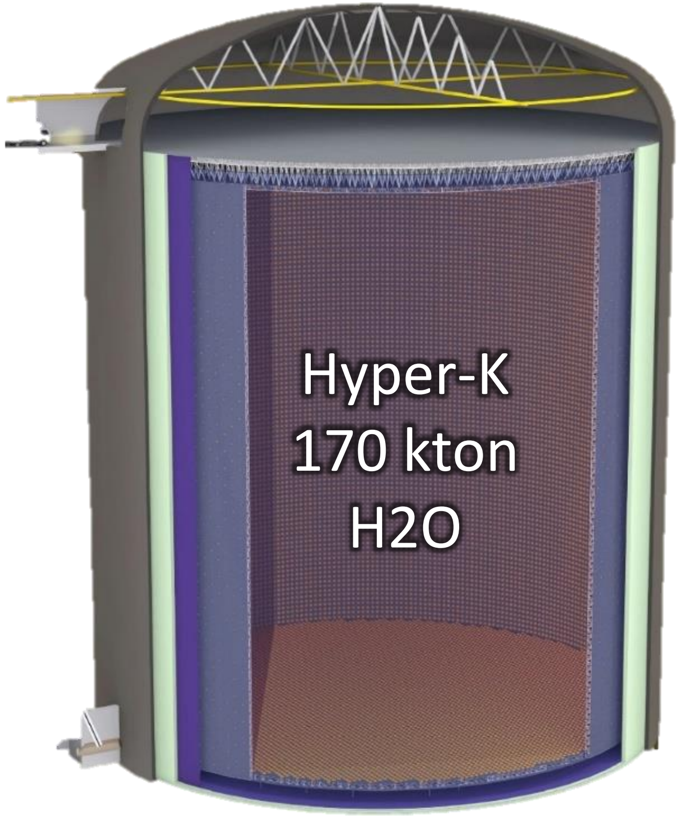
KamLAND: 1 kton x 4529 days

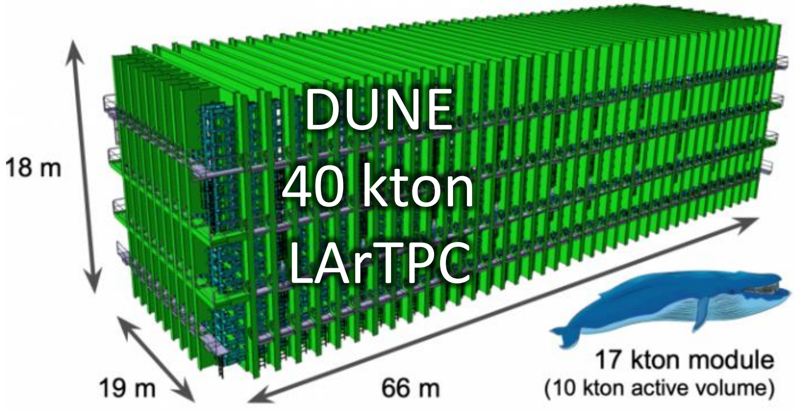


2023 ApJL **951** L27

DSNB Future Detection





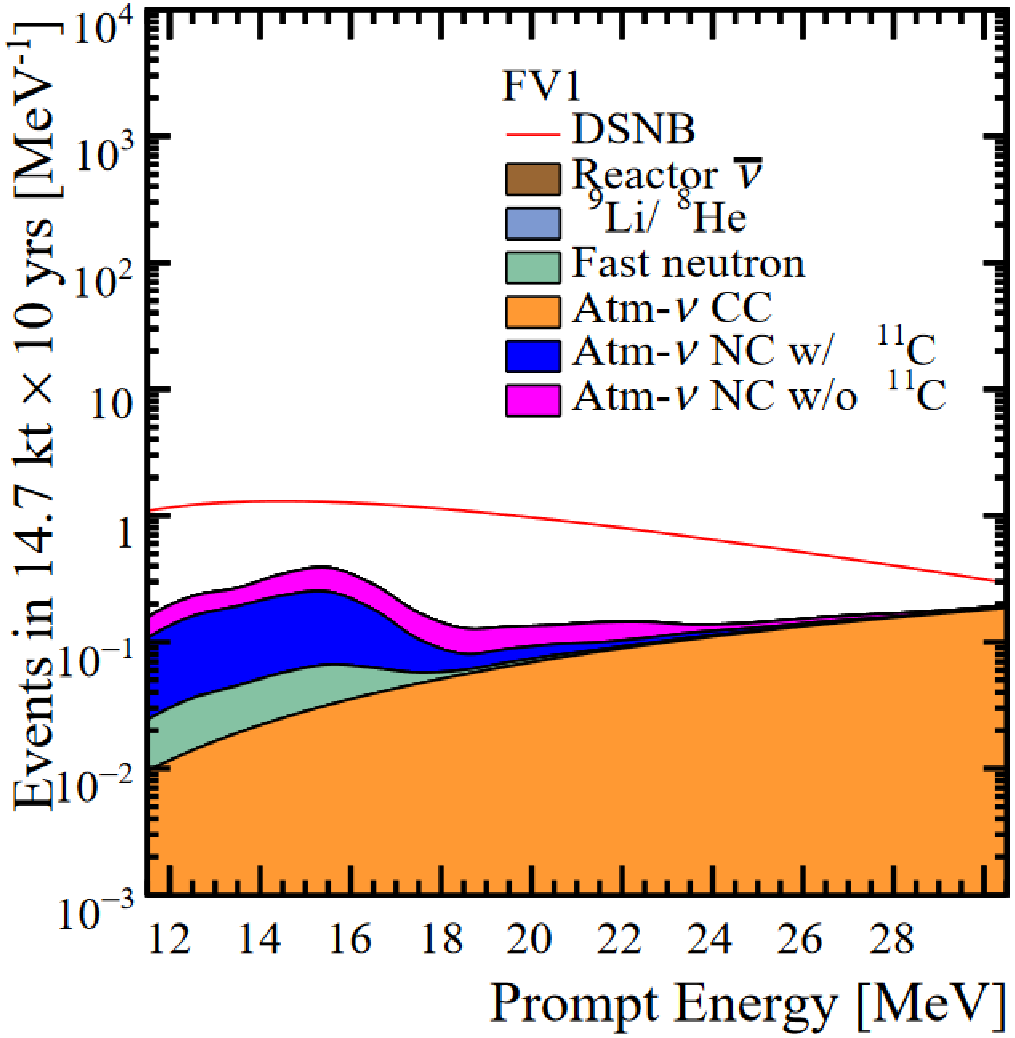


JUNO

JCAP 10 (2022) 033

- Fast neutron from n scatter + n capture
- Atmospheric NC: gamma rejected via LSD
- Atmospheric CC: intrinsic with low energy $\bar{\nu}_e$
- Spallation & Reactor: excluded from ROI

Efficiency: ~75%



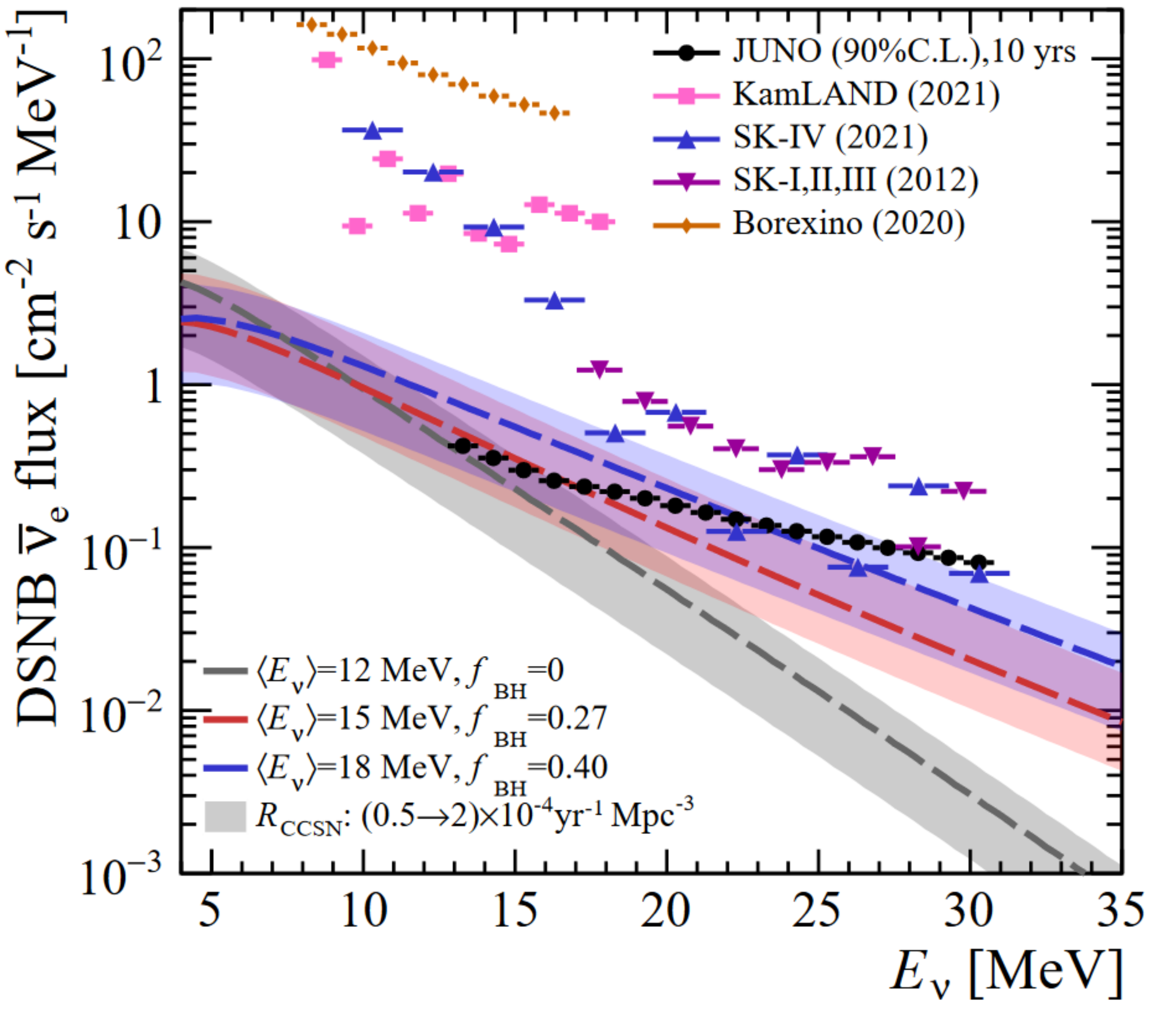
DSNB Limit

JCAP 10 (2022) 033

SK-IV: 22.5 kton x 2970 days

KamLAND: 1 kton x 4529 days

JUNO: 20 kton x 10 years

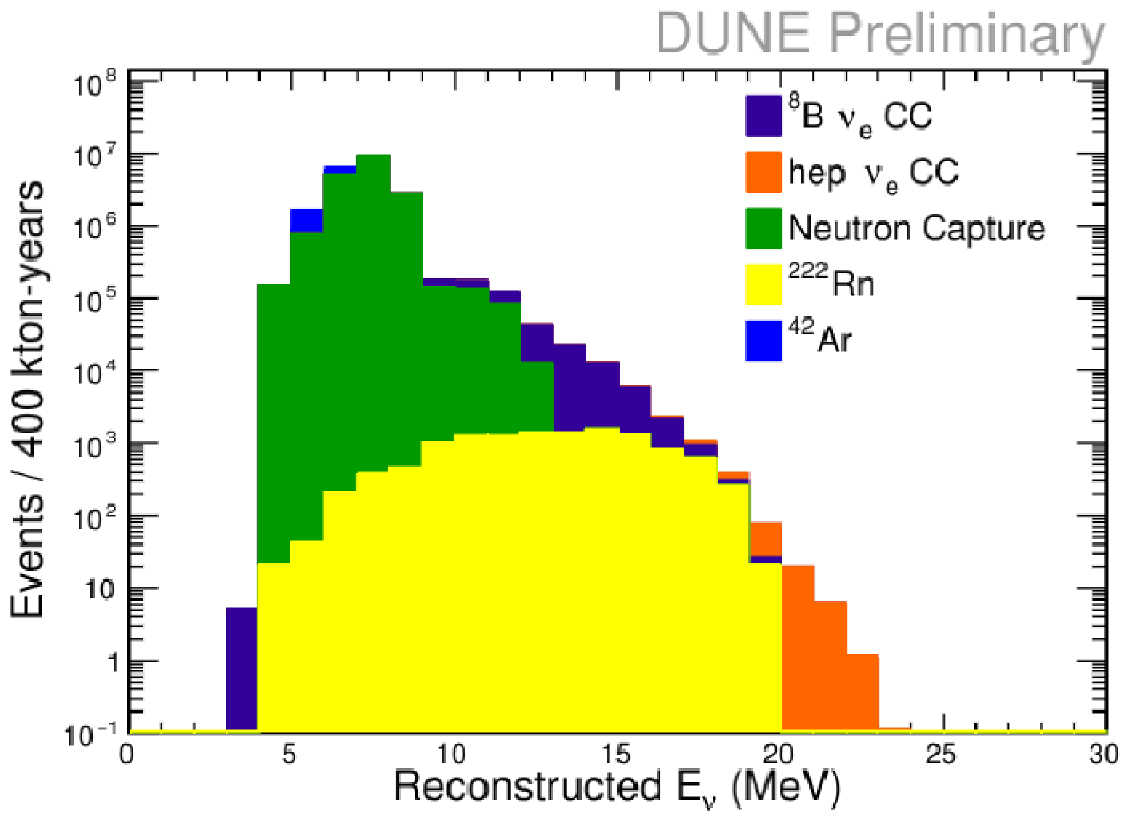


DUNE? A Discussion

- Signature:
  electron/positron + de-excitation γ
  $\nu_e/\bar{\nu}_e$ separation via de-excitation γ energy?

- Solar neurinos: if no $\nu_e/\bar{\nu}_e$ separation
- Atmospheric NC: γ/e separation?
- Atmospheric CC: low energy $\bar{\nu}_e$

Dan Pershey, CoSSURF 2024



Thank you