Status Report: DSNB Simulation and Background Estimation

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1. Diffuse Supernova Neutrino Background
2. Simulation Procedure and IBD Event Selection
3. Background Sources
4. Status and Results

Diffuse Supernova Neutrino Background

- the cumulative neutrino emission of core-collapse supernovae throughout the universe
- detection also via the inverse beta decay ($\bar{\nu}_e + p \rightarrow n + e^+$)
- calculation of the spectrum:

$$\frac{dR_\nu}{dE_\nu} = \frac{dF_\nu}{dE_\nu} \cdot \sigma_\nu(E_\nu) \cdot N_p,$$

with

- $\frac{dF_\nu}{dE_\nu}$ as the DSNB Flux,
- $\sigma_\nu(E_\nu)$ as the cross section for the IBD reaction,
- N_p as the number of protons in the target volume.

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DSNB Flux

$$\frac{dF_\nu}{dE_\nu} \propto R_{SN} \cdot \frac{dN_{\nu_e}(E'_\nu)}{dE'_\nu}$$

with the supernova rate R_{SN} and the neutrino spectrum $\frac{dN_{\bar{\nu}_e}}{dE_{\bar{\nu}_e}}$

$R_{SN} \propto R_*(z)$, depend on the star formation rate $R_*(z)$[1].

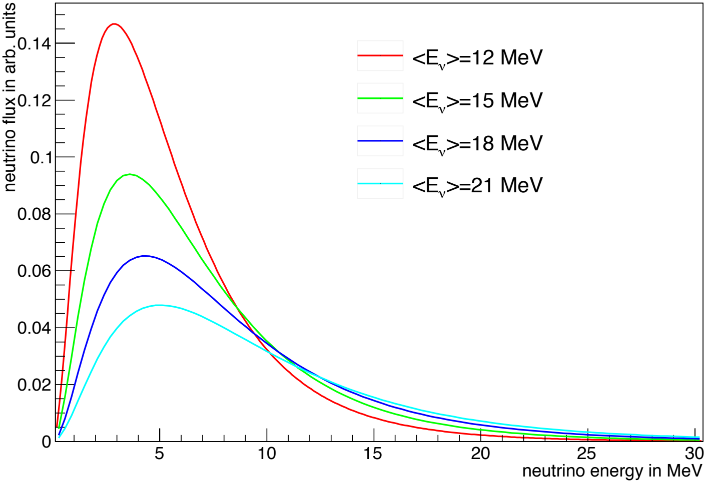
The neutrino spectrum follows a Maxwell Boltzmann distribution[2]:

$$\frac{dN_{\bar{\nu}_e}}{dE_{\bar{\nu}_e}} \propto \frac{1/6 \cdot L_\odot}{\langle E_{\bar{\nu}_e} \rangle} \frac{E^2_{\bar{\nu}_e}}{\langle E^3_{\bar{\nu}_e} \rangle} \exp^{-3E_{\bar{\nu}_e}/\langle E_{\bar{\nu}_e} \rangle},$$

with $L_\odot$ as the total luminosity of the sun, $\langle E_{\bar{\nu}_e} \rangle$ the mean neutrino energy and factor $1/6$ for electron antineutrinos

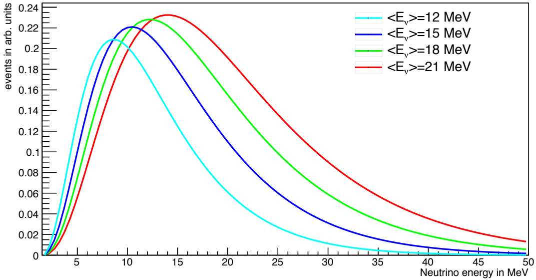
0 [1]Ando:2004hc, [2]Wurm:2011zn

DSNB Flux


neutrino flux in arb. units
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
5
10
15
20
25
30
neutrino energy in MeV
$<E_\nu>=12$ MeV
$<E_\nu>=15$ MeV
$<E_\nu>=18$ MeV
$<E_\nu>=21$ MeV

DSNB Spectrum

$$\frac{dR_\nu}{dE_\nu} = \frac{dF_\nu}{dE_\nu} \cdot \sigma_\nu(E_\nu) \cdot N_p$$



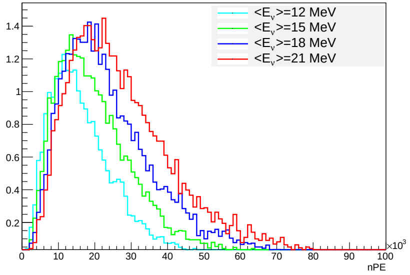
$< E_\nu >$ in MeV	DSNB events /**10 years** / 17 kt
12	28
15	36
18	44
22	55

DSNB Generator

- generate positron-neutron pairs
- direction of incoming neutrinos are homogeneously distributed
- input parameter for generator is mean neutrino energy: $< E_\nu >$

```
gu92zut@ges02:DSNB$ DSNB.exe --help
DSNB.exe [-seed seed] [-o outputfilename] [-n nevents] [-E_mean E_mean]
```

10k simulated events with $< E_\nu >= 12, 15, 18, 21$ MeV:



✓ distribution follows DSNB spectrum

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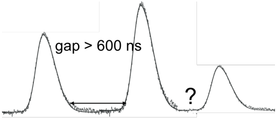
IBD Event Selection and Simulation

1. Physics simulation (detsim)
2. Selection of IBD-like events
   - **Fiducial volume cut:** Only accept events with $R < R_{max}$(16m)
   - **Time difference cut:** 600 ns $< \delta t^{\text{p-d}} <$ 1ms
   - **Neutron multiplicity cut:** two pulses in time window of 1 ms



   - **Neutron delayed energy cut**[1]: $|nPE_d - 3050| < 400$

[1] from simulating 1k homogeneously distributed 2.2 MeV gammas

IBD Event Selection and Simulation

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     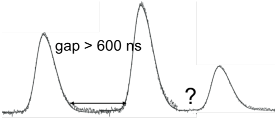

     → should be done within/after electronic simulation
   - **Neutron delayed energy cut**[1]: $|nPE_d - 3050| < 400$

     → update this with calib data

[1] from simulating 1k homogeneously distributed 2.2 MeV gammas

IBD Event Selection and Simulation

1. Physics simulation (detsim)
2. Selection of IBD-like events
3. Electronic simulation
4. Calibration
5. Reconstruction based on RecPSDAlg (Yu Xu), no vertex rec.

IBD Event Selection and Simulation

J17v1r2

1. Physics simulation (detsim)✓
2. Selection of IBD-like events✓
3. Electronic simulation
4. Calibration
5. Reconstruction based on RecPSDAlg (Yu Xu), no vertex rec.

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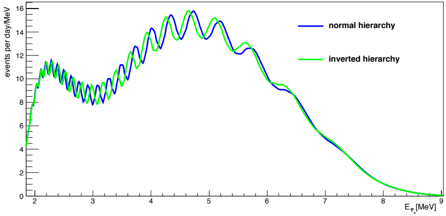
3. Background Sources
   - Reactor Neutrino Background
   - Atmospheric Neutral Current Background
   - Atmospheric Charged Current Background
   - Li9-Background
   - Fast Neutrons
4. Status and Results

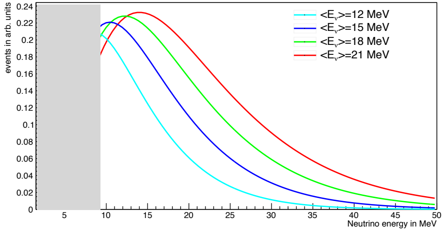
Reactor Neutrino Background

- $\sim$ 60 reactor neutrino events/d
  $\rightarrow$ 180k events in 10 years
  $(R_{reactor}/R_{DSNB} = 4500)$

$\rightarrow$ lower energy limit on the DSNB detection window

- simulation of 1k homogeneously distributed reactor neutrino events with $E > 9$ MeV





Reactor Neutrino Background

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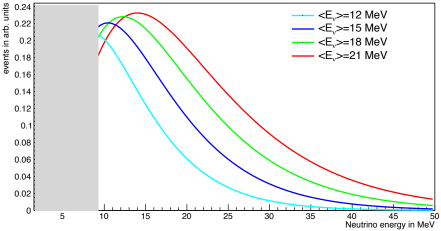

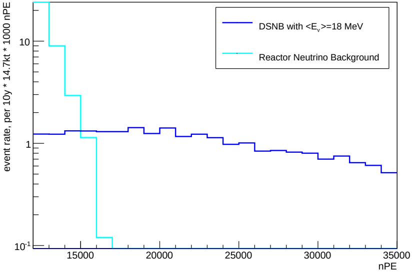

$\rightarrow$ better reactor neutrino model at higher energies

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Atmospheric Neutral Current Background

- NC reactions of atmospheric neutrinos and antineutrinos of all flavors pose a possible background
- reactions that can **mimic an IBD** event signature

Reaction channel			
$\nu_x + {}^{12}\mathrm{C} \longrightarrow \nu_x +$			
(1)	p	+	^{11}B
(2)	n	+	^{11}C
(3)	n+p	+	^{10}B
(4)	2p	+	^{10}Be
(5)	2n	+	^{10}C
(6)	n+2p	+	^{9}Be
(7)	2n+p	+	^{9}B
(8)	2n+2p	+	^{7}Be
(9)	2n+3p	+	^{7}Li

Atmospheric Neutral Current Background

Simulation

1. Interactions of atmospheric neutrinos inside the target volume

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$\nu_x + {}^{12}\mathrm{C} \longrightarrow \nu_x +$			
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Atmospheric Neutral Current Background

Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus

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Atmospheric Neutral Current Background

Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus
3. Simulation of final particles in JUNO

Reaction channel			
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Atmospheric Neutral Current Background

- GENIE V2.12.4
- atmospheric neutrino flux: HKKM (Honda) flux for JUNO location[1]

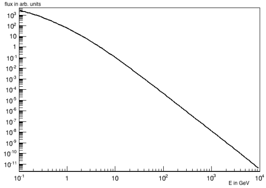
Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus
3. Simulation of final particles in JUNO

[1] http://www.icrr.u-tokyo.ac.jp/mhonda/nflx2014/index.html

Atmospheric Neutral Current Background

- GENIE V2.12.4
- atmospheric neutrino flux: HKKM (Honda) flux for JUNO location[1]
  - flavors: $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$
  - angle dependent
  - solar activities (min and max)
  - energy range: 100 MeV - 4000 GeV



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Atmospheric Neutral Current Background

- GENIE V2.12.4
- atmospheric neutrino flux: HKKM (Honda) flux for JUNO location[1]
- LS target [2]
- Cross section from Genie [3]

Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus
3. Simulation of final particles in JUNO

[1] http://www.icrr.u-tokyo.ac.jp/mhonda/nflx2014/index.html
[2] offline/Detector/Geometry/share/CdGeom.gdml
[3] hepforge.org/archive/genie/data/2.12.0/DefaultPlusMECwithNC/gxsplFNALsmall.xml

Atmospheric Neutral Current Background

Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus
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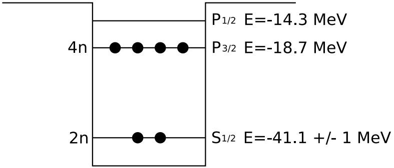
Atmospheric Neutral Current Background

- probability that the resulting nucleus is in excited state $\approx 1/3$
- simple shell model of $^{12}\mathrm{C}$ neutrons



- $E_{\mathrm{atm}\nu s} >> E_{\mathrm{binding}}$(nucleons) $\rightarrow$ assume that interaction probability for atmospheric neutrino is the same for each nucleon

$\rightarrow$ probability that nucleus has a hole in the $S_{1/2}$ shell can be approximated through $2/6 = 1/3$

Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus

Atmospheric Neutral Current Background

- based nuclear reaction program TALYS ($\rightarrow$ Jie Cheng)

$$
\begin{aligned}
\nu_{\mathrm{X}} + {}^{12}\mathrm{C} \quad &\longrightarrow \quad \nu_x + n + {}^{11}\mathrm{C}^* \\
{}^{11}\mathrm{C}^* \quad &\longrightarrow \quad p + \alpha + {}^{6}_{3}\mathrm{Li}
\end{aligned}
$$

Channel	GammaEner	NeutronEn	ProtonEne	DeuteronE	TritiumEn	Helium3En	AlphaEner
13			3.0970588				9.4173469

C11decayP.root

- γ energy for ResNuclZ=6 and ResNucA=3

ResNuclZ	ResNuclA	ResNuclLevel	ResNuclEnergy	ResNuclPopulation
3	6	0	0	1.435
3	6	1	2.186	0.2521
3	6	2	3.563	0.1255
3	6	3	4.312	0.151
3	6	4	5.366	0.1024
3	6	5	5.65	0.1017
3	6	6	15.8	0.0001363
3	6	7	17.985	1.265e-05
3	6	8	21.5	0
3	6	9	23	0
3	6	10	24.779	0

C11decayGammaP.root

Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus

Atmospheric Neutral Current Background

Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus
3. Simulation of final particles in JUNO[a]

[a] reads GENIE Files with GtGstTool

Atmospheric Neutral Current Background

$$\begin{aligned} \nu_x + {}^{12}_{6}\mathrm{C} &\longrightarrow \nu_x + 2\,\mathrm{p} + n + {}^{9}_{4}\mathrm{Be}^* \\ {}^{9}_{4}\mathrm{Be}^* &\longrightarrow {}^{3}_{1}\mathrm{H} + {}^{6}_{3}\mathrm{Li}^* \\ {}^{6}_{3}\mathrm{Li}^* &\longrightarrow {}^{6}_{3}\mathrm{Li} + \gamma \end{aligned}$$

```
gun.mutate          _INFO: Using neutrino event generator filter nc==1&&!coh==1&&calresp0<0.05
gun.mutate          _INFO: Deexitation - add Particle 1000010030 with Energy: 6.2817
gun.mutate          _INFO: Deexitation - add Particle 22 with Energy: 5.366
**********************************************************
* nInitParti *      PDGID *    TrackID *       edep *
**********************************************************
*          6 *         14 *          1 *          0 *
*          6 *       2112 *          2 * 0.19758190 *
*          6 *       2212 *          3 *          0 *
*          6 *       2212 *          4 * 18.4408912 *
*          6 * 1000010030 *          5 * 6.27469253 *
*          6 *         22 *          6 * 5.36600065 *
**********************************************************
```

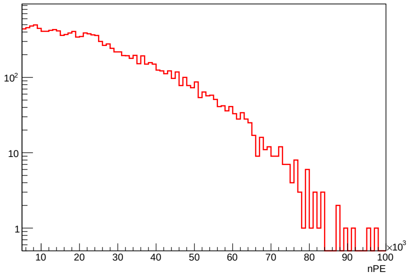
Simulation

1. Interactions of atmospheric neutrinos inside the target volume
2. Deexcitation of the resulting nucleus
3. Simulation of final particles in JUNO[a]

[a] reads GENIE Files with GtGstTool

Atmospheric Neutral Current Background

- GENIE simulation: $2 \cdot 10^6$ atmospheric neutrino events ($E_\nu < 10$ GeV)
- preselection: NC and QEL ($\rightarrow 20\% \approx 400$k events)
- 20k events simulated with offline out of preselected events



$\rightarrow$ expected rate calculation ongoing

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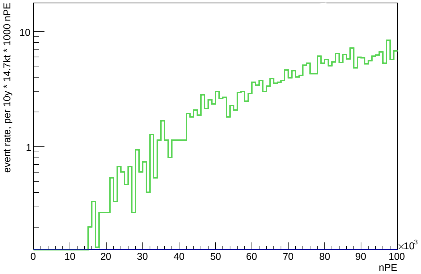
4. Status and Results

Atmospheric Charged Current Background

- GENIE output ($1 \cdot 10^6$ events) of $\bar{\nu}_e$ reactions on H
  - assume that muons can be tagged $\rightarrow$ no simulation of ν_μ, $\bar{\nu}_\mu$
  - $\nu_e + n \rightarrow p + e^- \rightarrow$ no neutron
  - $\bar{\nu}_e$ CC reaction on $^{12}C \rightarrow {}^{12}\mathrm{B} + e^+ \rightarrow$ no neutron

Atmospheric Charged Current Background

- GENIE output ($1 \cdot 10^6$ events) of $\bar{\nu}_e$ reactions on H
- preselection: $E_\nu < 100$ MeV and CC $\rightarrow$ 75k events
- simulation of 10k AtmCC events (out of 75k events)

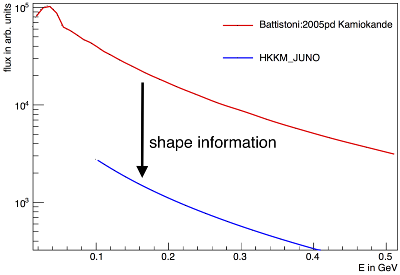


$\rightarrow$ GENIE can simulate neutrinos with $E_\nu < 100$ MeV, although flux file has no information in this energy region

$\rightarrow$ How does GENIE treat this scenario?

Rate Estimation

- use shape information of atmospheric neutrino flux[4] between 10 MeV and 1 GeV

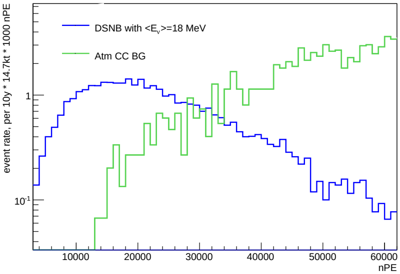


[4]Fluka: Battistoni:2005pd

Rate Estimation

- use shape information of atmospheric neutrino flux[4] between 10 MeV and 1 GeV
- cross section from Genie (qel-cc-p)

$\rightarrow$ $R_{CC} = 325 \left(\frac{R_{FV}}{16.78}\right)^3$ events per 10y

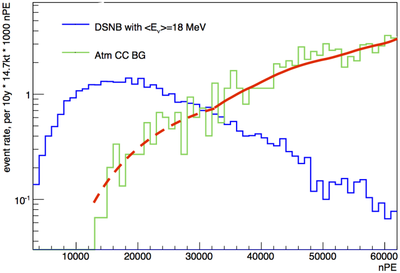


[4] Fluka: Battistoni:2005pd

Rate Estimation

Irreducible Background!

→ get information of AtmCC background from higher energy range
→ subtract the background from the data



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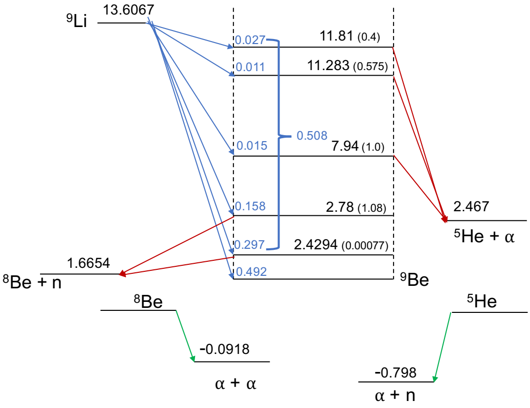
^{9}Li Background

- cosmogenic isotopes that are produced by cosmic muons in the LS
- ^9Li can decay via β^- decay ($T_{1/2} = 178$ ms) into excited state (50.8%) of ^{9}Be

$\rightarrow$ prompt signal

- excited states decay into $2\alpha + n$

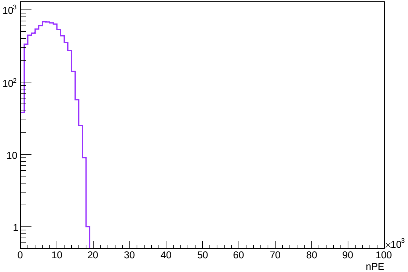
$\rightarrow$ delayed signal

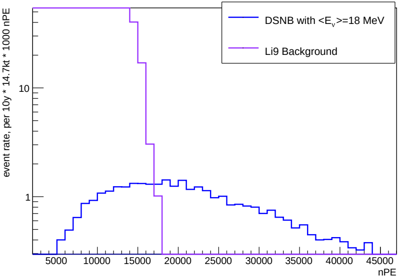


[0] decay scheme based on http://www.tunl.duke.edu/nucldata

Simulation of ^{9}Li Background

- simulate 10k β-decays into excited state
- Li9.exe based on *DetSimV2/PhysSim/Li9He8Decay.cc* [4]





$\rightarrow$ ^{9}Li signal sets lower energy limit

[4] gendecay Li9: no subdecays implemented

^{9}Li Background Rate

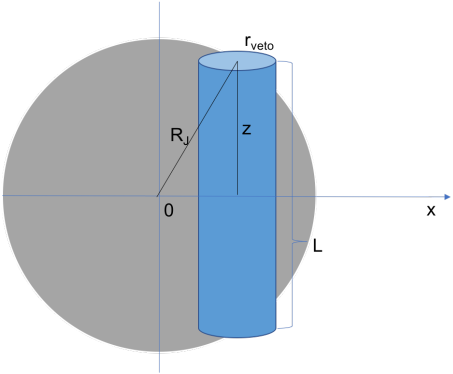
- based on KamLand[5] results: $Y_{^9Li} = 2.2 \cdot 10^{-7} \mu^{-}1 g^{-1} cm^2$
- muon rate in LS:
  - $R_\mu = 3.6$ Hz
  - mean muon track length $L_\mu = 23$ m

$$\rightarrow R = 2.44 \cdot 10^{-8} \cdot R^3_{FV} [cm^3] \overset{16m}{=} 100 \text{ per day}$$
$$R^{\beta-n} = BR \cdot R = 0.508 \cdot R = 51 \text{ per day}$$

[5] Abe:2009aa

Fiducial Volume Cut

- $^{9}\mathrm{Li}$ production close to muon track
- possible to veto a cylinder with $r_{veto} = 3$m around muon track for certain time $t_{veto} = 1.2s$
- dead time of the detector $t_{dead} \approx 0.14$



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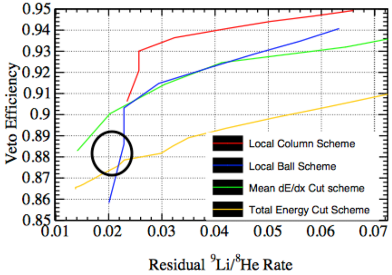
- dead time of the detector $t_{dead} \approx 0.14$
- residual ^{9}Li rate $\approx 2\%$

$\rightarrow$ $R^{\beta-n} = 51 \cdot 0.02 \approx 1$ per day

Kun Zhang DocDB #1366



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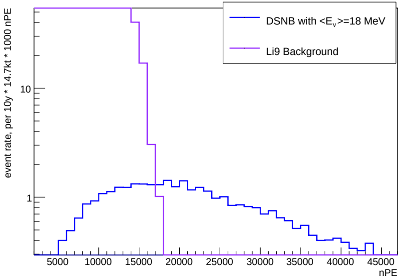
$\rightarrow$ $R^{\beta-n} = 51 \cdot 0.02 \approx 1$ per day



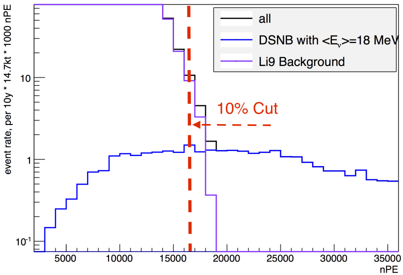
Reducible Background

$\rightarrow$ pulse shape analysis: get positron/electron discrimination efficiency through implementation of ortho-positronium-lifetime

Fiducial Volume Cut

- ^{9}Li production close to muon track
- possible to veto a cylinder with $r_{veto} = 3$m around muon track for certain time $t_{veto} = 1.2s$
- dead time of the detector $t_{dead} \approx 0.14$
- residual ^{9}Li rate $\approx 2\%$

$\rightarrow$ $R^{\beta-n} = 51 \cdot 0.02 \approx 1$ per day



Reducible Background

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1. Diffuse Supernova Neutrino Background

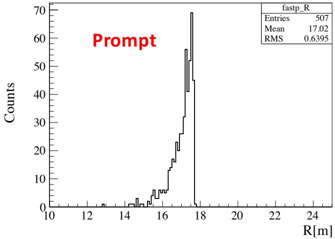
2. Simulation Procedure and IBD Event Selection

3. Background Sources
   - Reactor Neutrino Background
   - Atmospheric Neutral Current Background
   - Atmospheric Charged Current Background
   - Li9-Background
   - Fast Neutrons

4. Status and Results

Fast Neutron BG

- produced by cosmic muons in the surrounding rock (invisible for muon veto)
  - prompt signal: neutron scattering reactions (obtain energy of fast neutron)
  - delayed signal: capture of the thermalized neutron
- flat energy distribution with[6]: $R_{year} = 3.4$ between 11 and 30 MeV
- radial dependency: $R_{FastN} = 1.32 \cdot 10^{-17} \exp\left(2.05 \cdot R_{FV}[m]\right)$ per day



[6] Jie Cheng (DocDB #2274)

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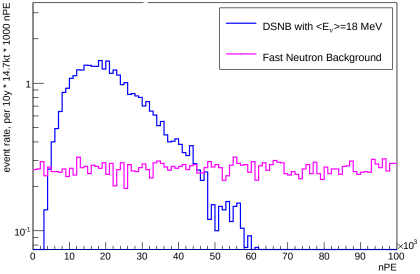

→ PSD: discrimination efficiency of protons and positrons

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1. Diffuse Supernova Neutrino Background
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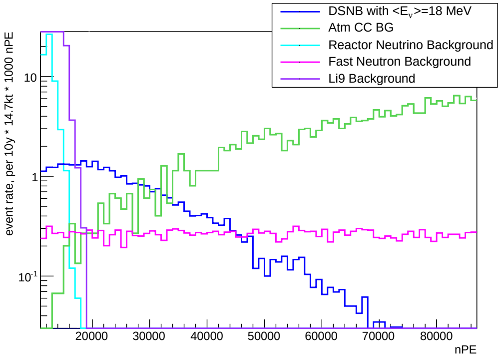
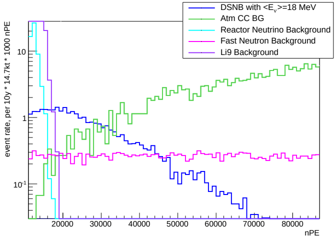
4. Status and Results

Preliminary Results

- 10k DSNB events
- (20k atmospheric NC events) $\rightarrow$ Rate + PDS!!!
- 10k atmospheric CC events ($E_\nu < 100$ MeV)
- 10k $^{9}\mathrm{Li}$-β-n decays
- 1k reactor neutrino events (> 9 MeV)



Proposal for DSNB Detection Strategy



AtmCC	measure spectrum in the dominant energy region for extrapolation to lower energies
AtmNC	PULSE SHAPE DISCRIMINATION!!!!
reactor νs	sets lower energy cut
^{9}Li	sets lower energy cut
fast neutrons	subdominant, subtract statistically (rate information from position dependency), important for AtmCC extrapolation

Proposal for DSNB Detection Strategy

Thank you!

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SFB 1258 | Neutrinos Dark Matter Messengers

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