# Supernova relic neutrinos at Jinping

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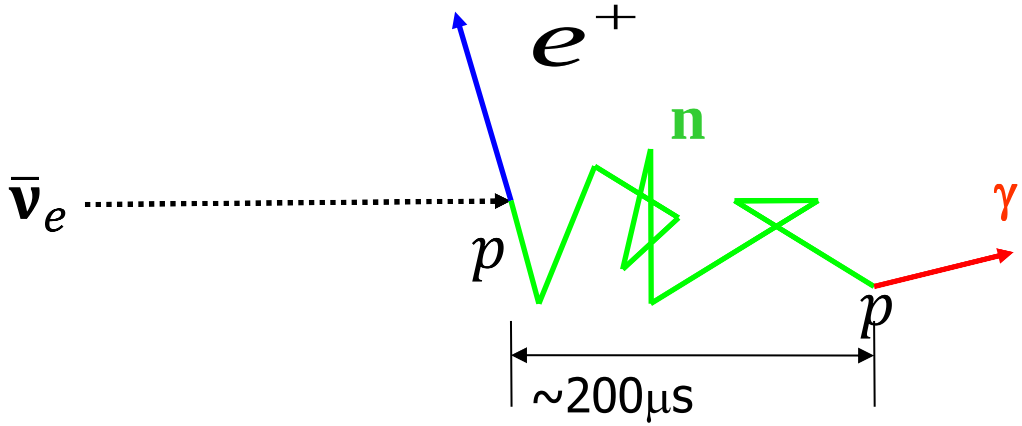
Jinping Workshop
June. 5th, 2015

# Outline

- **Detection of supernova relic neutrinos (SRN) $\bar{\nu}_e$**
- **Sensitivity studies at Jinping**
  - Liquid scintillator
  - Water
  - Water-based liquid scintillator
- **Summary**

# $\bar{\nu}_e$ detection method

- Detection via inverse-beta-decay (IBD) reaction:

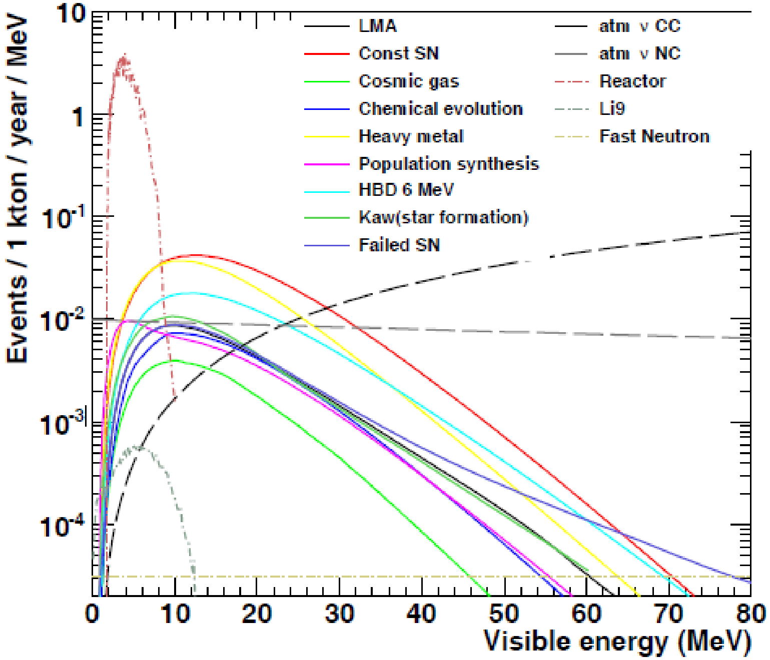



- Neutron lifetime: ~200 $\mu s$ in LS, water, WbLS

- Delayed coincidence: a prompt $e^+$ and a delayed $n$

# Background Sources

- Accidentals
  - PMT
  - Environmental or internal radioactivities
- Reactor neutrinos
- Solar neutrinos($\nu_e$ only)
  - B8 and hep
- Cosmic-induced background
  - Fast neutron
  - He8/Li9
- Atmospheric neutrinos
  - CC
  - NC




10-30 MeV

# Sensitivity study for liquid scintillator

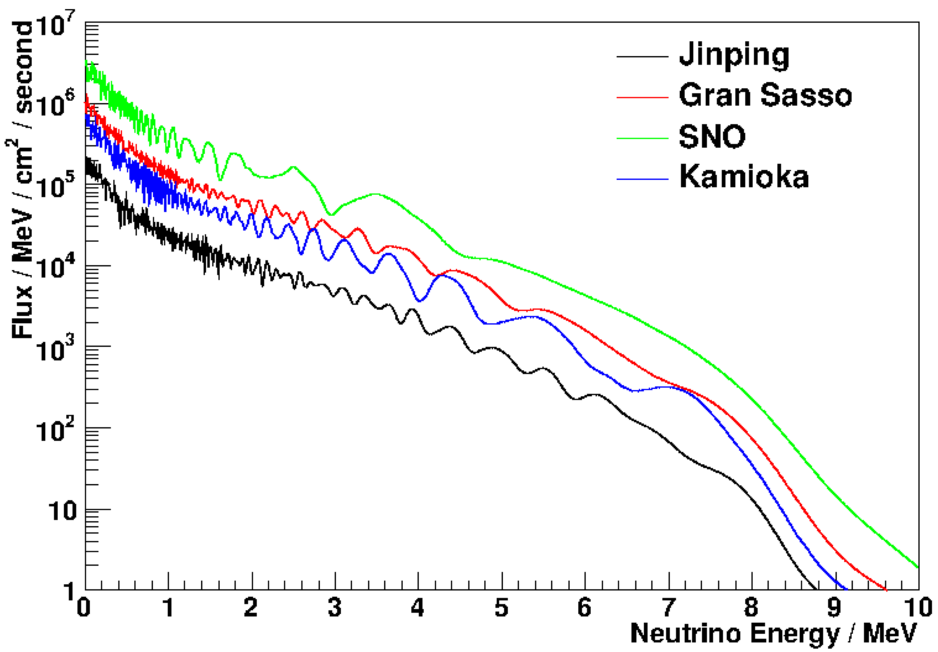
# Accidental coincidence

- Uncorrelated events could coincide to pass the $\bar{\nu}_e$ identification.

- The accidental coincidence events can be negligible compared with other backgrounds, due to the JinPing location.

# Reactor neutrinos

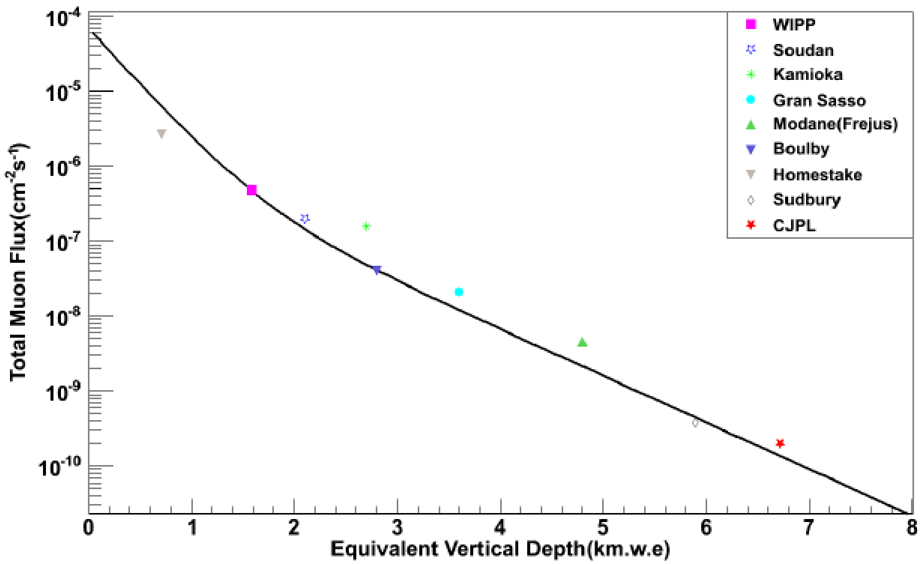
- Reactor neutrinos: $\bar{\nu}_e$
- Reactor neutrinos have an energy up to ~10 MeV, which determine the lower bound of SRN search.




- Above 10 MeV, the reactor neutrinos can be negligible, due to the JinPing location.

# Fast neutrons

- Fast neutrons are produced by cosmic-ray muons.
- Event signature: Prompt (recoiled proton) + delayed (neutron)
- Muon rate at JinPing is ~1,000 lower than that in Kamland.

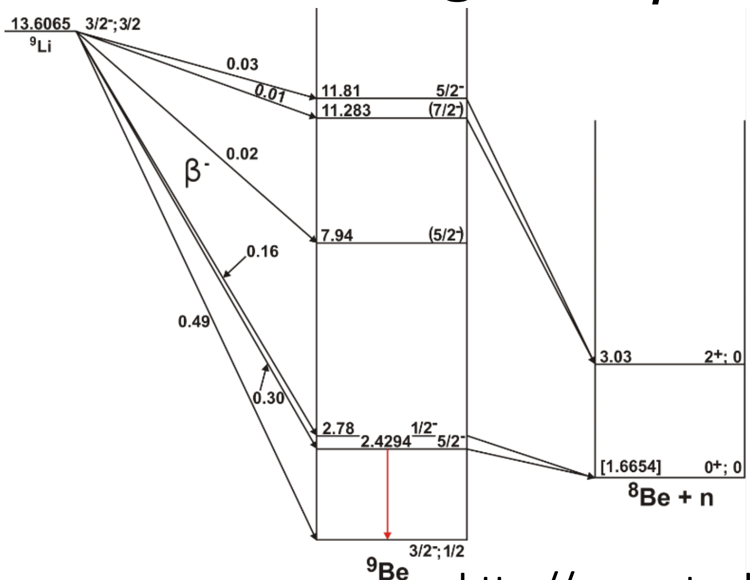


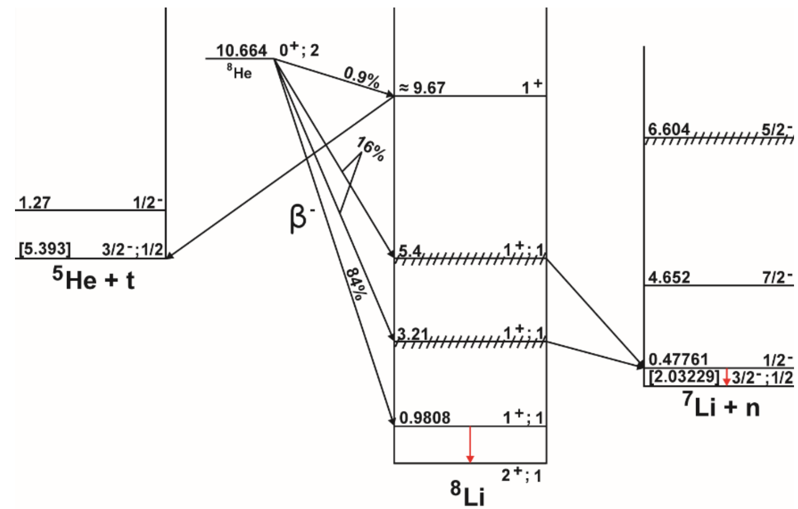

| | Kamland | JinPing |
|---|---|---|
| **Event rate(/kton/year)** | $\mathbf{0.7 \pm 0.7}$ | $\mathbf{(0.7 \pm 0.7) \times 10^{-3}}$ |

Kamland: *The Astrophysical Journal, 745:193(2012)*

# Spallation He8/Li9

- Cosmic-ray muon induced He8/Li9 can mimic the IBD reaction through the $\beta n$ decay.




http://www. tunl. duke. edu/nucldata/GroundStatedecays/

| | Kamland | JinPing |
|---|---|---|
| **Event rate(/kton/year)** | **~1.0** | $\mathbf{1.0\times 10^{-3}}$ |

Kamland: *The Astrophysical Journal, 745:193(2012)*

# Atmospheric neutrino CC

- Atmospheric neutrinos limits the upper bound to ~30 MeV for the SRN search.
- Atmospheric neutrinos: $\bar{\nu}_e$ CC
- Atmospheric neutrinos $\bar{\nu}_\mu/\nu_\mu$ CC: removed by a triple coincidence with $\mu - e - n$. However, some survive the cuts due to the inefficiency.

| Reaction |
|---|
| $\overline{\nu}_\mu + p \rightarrow \mu^+ + n$ |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \rightarrow \mu^+ + n + {}^{11}\mathrm{B}$ |
| $\nu_\mu + {}^{12}\mathrm{C} \rightarrow \mu^- + n + {}^{11}\mathrm{N}$ |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \rightarrow \mu^+ + n + {}^{11}\mathrm{B} + \gamma$ |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \rightarrow \mu^+ + n + {}^{7}\mathrm{Li} + \alpha$ |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \rightarrow \mu^+ + 2n + {}^{10}\mathrm{B}$ |

Kamland: *The Astrophysical Journal, 745:193(2012)*

| | $\bar{\nu}_e$ CC | $\bar{\nu}_\mu$ CC | CC(total) |
|---|---|---|---|
| **Event rate(/kton/year)** | **~0.02** | **~0.2** | **~0.2** |

# Atmospheric neutrino NC

- Atmospheric neutrinos NC: Neutrinos interact with carbon can eject a neutron(<200 MeV), leaving the carbon (C11*) in the excited state with multiple decay modes.

| Reaction |
|---|
| $\nu(\overline{\nu})+{}^{12}\mathrm{C}\rightarrow\ \nu(\overline{\nu})+n+{}^{11}\mathrm{C}+\gamma$ |
| $\nu(\overline{\nu})+{}^{12}\mathrm{C}\rightarrow\ \nu(\overline{\nu})+n+{}^{10}\mathrm{B}+p$ |
| $\nu(\overline{\nu})+{}^{12}\mathrm{C}\rightarrow\ \nu(\overline{\nu})+n+{}^{6}\mathrm{Li}+\alpha+p$ |
| $\nu(\overline{\nu})+{}^{12}\mathrm{C}\rightarrow\ \nu(\overline{\nu})+n+{}^{9}\mathrm{Be}+2p$ |
| $\nu(\overline{\nu})+{}^{12}\mathrm{C}\rightarrow\ \nu(\overline{\nu})+2n+{}^{10}\mathrm{C}$ |

Kamland: *The Astrophysical Journal, 745:193(2012)*

- 2/3 of C11* is in the ground state. C11 can be tagged by $\beta$ decay with $\tau=29$ min and Q=2 MeV.
- 1/3 of C11* decays with $p, n, \alpha$, which can be removed by pulse shape discrimination.

→ a factor of 1./(5%+1%)=16 suppression.

R. Moellengberg *PhD thesis, (2009)* ; *Astropart phys. 35, 685 (2012)*

| | Kamland | JinPing |
|---|---|---|
| **Event rate(/kton/year)** | **3.6** | **0.2** |

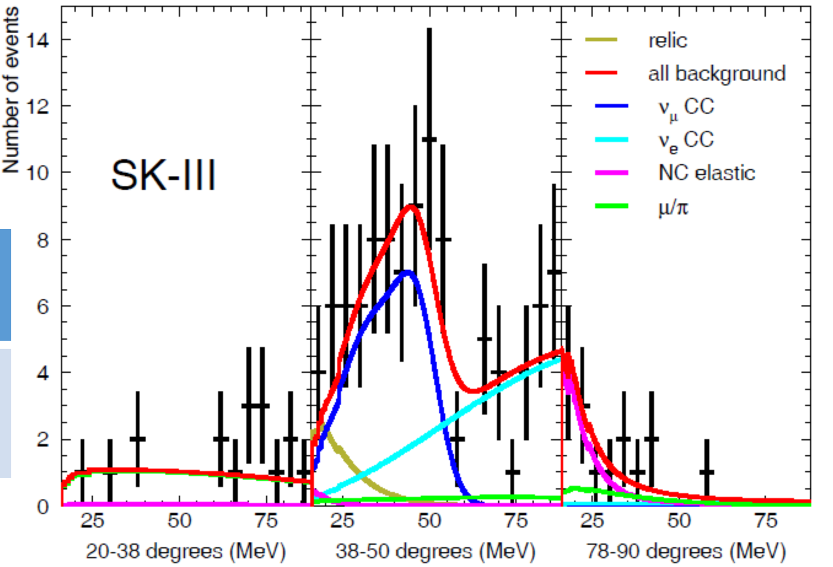
# Sensitivity study for water

# Atmospheric neutrino CC

- atmospheric neutrinos $\bar{\nu}_e$ CC
- atmospheric neutrinos $\bar{\nu}_\mu$ CC: $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$ ; the produced $\mu$ could be below Cherenkov threshold. Thus, the decay-e cannot be tagged.

*PRD 85, 052007 (2012)*

| | $\bar{\nu}_e$ **CC** | $\bar{\nu}_\mu$ **CC** | **CC(total)** |
|---|---|---|---|
| **Event rate (/20kton/year)** | **~0.6** | **~3.4** | **~4.0** |




Blue: $\nu_\mu/\ \bar{\nu}_\mu$ CC

# Atmospheric neutrino NC

- NC elastic scattering:

$$\nu + n \rightarrow \nu + n$$

- Event signature: prompt (gamma rays from interaction of outgoing neutron on oxygen) + delayed (neutron)

- Event rate: 1$\pm$1 events/20kton/year

# Sensitivity study for water-based liquid scintillator

# Better particle identification

- WbLS has a better particle identification for low energy $p$, $n$, $\alpha$, and $\mu$ than scintillator, since they cannot produce the Cherenkov light.

| Reaction | Atm CC |
|---|---|
| $\overline{\nu}_\mu + p \to \mu^+ + n$ | |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \to \mu^+ + n + {}^{11}\mathrm{B}$ | |
| $\nu_\mu + {}^{12}\mathrm{C} \to \mu^- + n + {}^{11}\mathrm{N}$ | |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \to \mu^+ + n + {}^{11}\mathrm{B} + \gamma$ | |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \to \mu^+ + n + {}^{7}\mathrm{Li} + \alpha$ | |
| $\overline{\nu}_\mu + {}^{12}\mathrm{C} \to \mu^+ + 2n + {}^{10}\mathrm{B}$ | |

| Reaction | Atm NC |
|---|---|
| $\nu(\overline{\nu}) + {}^{12}\mathrm{C} \to \nu(\overline{\nu}) + n + {}^{11}\mathrm{C} + \gamma$ | |
| $\nu(\overline{\nu}) + {}^{12}\mathrm{C} \to \nu(\overline{\nu}) + n + {}^{10}\mathrm{B} + p$ | |
| $\nu(\overline{\nu}) + {}^{12}\mathrm{C} \to \nu(\overline{\nu}) + n + {}^{6}\mathrm{Li} + \alpha + p$ | |
| $\nu(\overline{\nu}) + {}^{12}\mathrm{C} \to \nu(\overline{\nu}) + n + {}^{9}\mathrm{Be} + 2p$ | |
| $\nu(\overline{\nu}) + {}^{12}\mathrm{C} \to \nu(\overline{\nu}) + 2n + {}^{10}\mathrm{C}$ | |

- Conservatively the majority of CC and NC bkg. can be suppressed by a factor of 2
- Optimistically they can be suppressed by a factor of 10

# Summary of signal and backgrounds

10-30 MeV

| Event rate (/20kton/year) | scintillator | water | WbLS Conservative | WbLS optimistic |
|---|---|---|---|---|
| SRN signal | 1-13 | | | |
| Accidental | 0 | 0 | 0 | 0 |
| Reactor | 0 | 0 | 0 | 0 |
| Fast neutron | 0 | 0 | 0 | 0 |
| He8/Li9 | 0 | 0 | 0 | 0 |
| Atmospheric CC | 4 | 4 | 2 | 0.4 |
| Atmospheric NC | 4 | $1 \pm 1$ | 2 | 0.4 |
| Total background | 8 | 5 | 4 | 0.8 |

# Summary

- The sensitivity on SRN search using scintillator, water and WbLS is discussed. It is expected to give the world best flux upper limits, after several years data taking.

- Optimistically the observation of SRN would be possible.

# Thanks for your attention!

# BACK UP

# Muon issue

- Muons passing surrounding rock are main cause for fast neutrons to be problematic.
- The surface area ratio should be close between JinPing and Kamland due to the close target mass.
- Yield: $\left(\frac{E_{JinPing}}{E_{Kamland}}\right)^{0.77}$, ~350 GeV average at JinPing and ~260 GeV average at Kamland. Thus, the increase is not significant.

# GADZOOKS!

- Target  mass: 50 kton  water(FV=22.5 kton)
- GADZOOKS! has proposed to add 0.2% gadolinium in to SK, which could greatly increase the signal-to-noise ratio of neutron tagging.
- Expected signal and background ($E_{\overline{\nu}_e}$: 10-30 MeV):

| | Li9 | ATM CC | ATM NC |
|---|---|---|---|
| **Event rate (/22.5kton/year)** | $2.3 \pm 0.3 \pm 0.5$ | **~4** | $1 \pm 1$ |

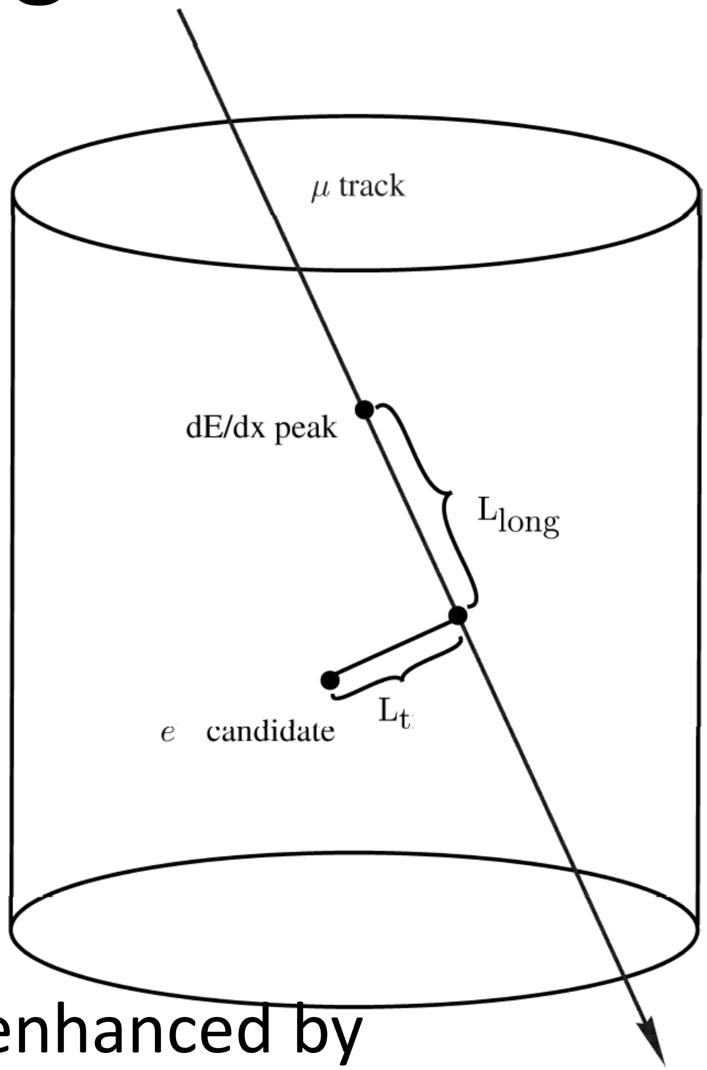
# LENA

- Target  mass: 50 kton  LS (4800 m.w.e., 2 orders less than the muon rates of Kamland)

# Spallation background

- Spallation backgrounds can be removed by simply assuming 1 min veto to a muon, since the longest lifetime of isotopes is ~20 s.

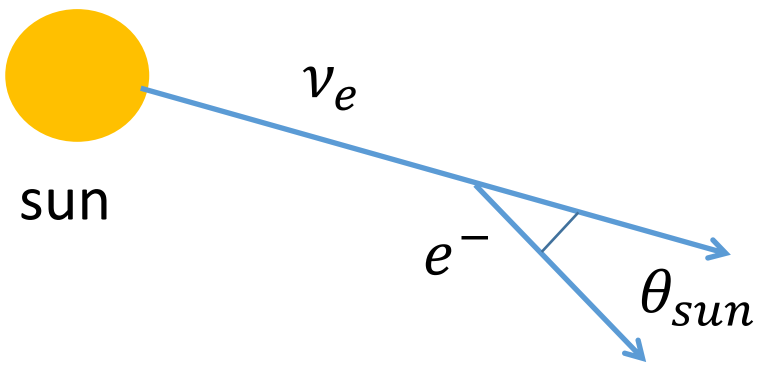
- Muon rate ~$2\times 10^{-3}$ Hz(assuming 50 kton target mass, FV~20 kton), 1 min veto could induce ~12% dead time. All spallation backgrounds are removed to a negligible level.




- This dead time could be greatly enhanced by reconstructing the muon track

# Solar neutrinos

- Solar neutrinos: $\nu_e$ only; $\nu_e + \mathrm{e}^- \rightarrow \nu_e + e^-$ ; The scattered $e^-$ records the incident direction information of $\nu_e$.




- Solar neutrinos can be removed by a solar angle cut and the identification of IBD events. Thus, they can be reduced to a negligible level.