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Low Energy Study for Korean Detector Option

Contribution for this study by
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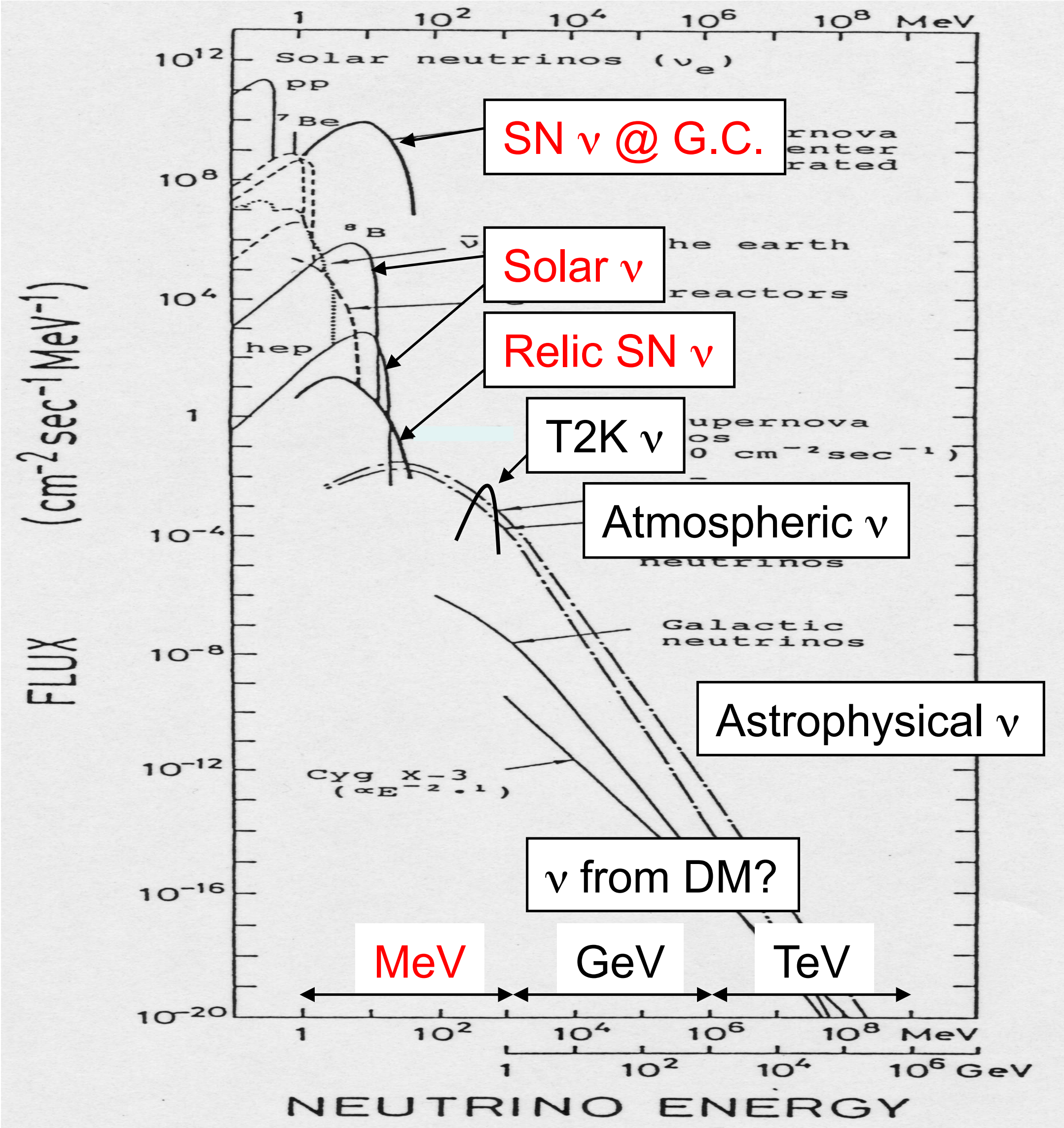
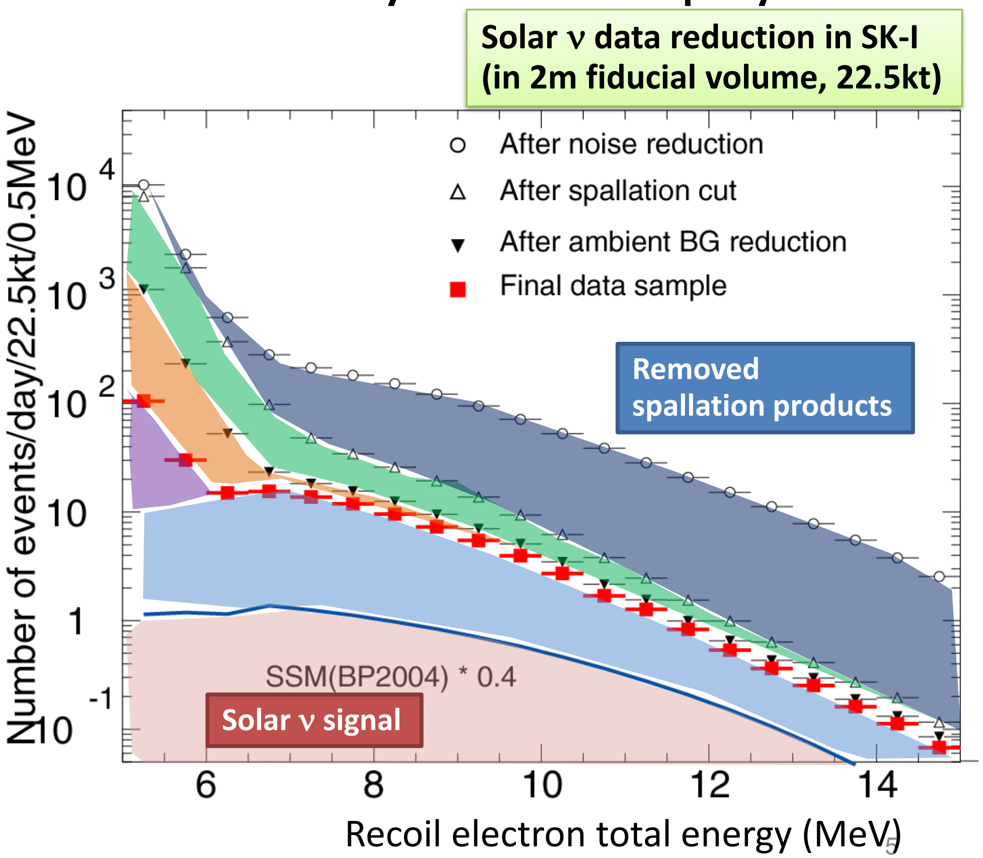
16 Feb., 2017

Neutrino sources



Low Energy Physics at Korean Site

- With an identical detector, all the low energy physics programs considered at Kamioka would be possible at HK in Korea.
  - e.g. solar, supernova burst, supernova relic neutrinos.
- Because the dominant background in 10-20 MeV comes from muon spallation products, deeper site in Korea will improve the sensitivity on these physics.



- Solar ν signal, removed and remaining spallation products backgrounds.

Studies for Low Energy Physics at Korea Site

- We're carrying out following studies for HK at Korea site.
  - Studies for Korea sites (e.g. solar sensitivity at Korea site) are better to be taken over by other people (e.g. Korean group) in future.

1. Muon flux simulation study (I. Shimizu[Tohoku])
   1. Simulation for Muons going through the mountain.
   2. Radioactive isotope production by muon spallation.

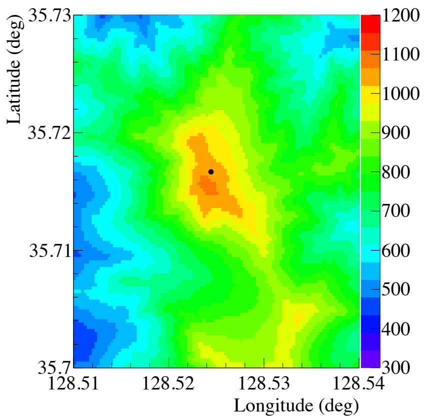
2. Sensitivity of physics analysis (T. Yano[Kobe], Y. Koshio[Okayama])
   1. Calculation of signal efficiency/BG reduction with spallation at each site.
   2. Estimation of physics sensitivity.

Muon Flux at HKK Candidate Sites

- Mt. Bisul and Mt. Bohyun are studied.
  - Based on the positions given in the white paper, elevation data are extracted from a database.
  - 820m and 1000m overburden are assumed for both sites.
- Simulation of the muon flux at each site and muon spallation in the water was performed.

Digital Elevation Data : Mt. Bisul

Elevation data (**30 m mesh**)
around peak of Mt. Bisul



Peak 1084 m

simulation condition

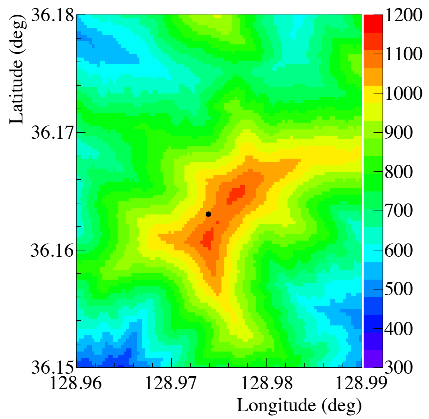
Surface muon flux	Modified Gaisser model A. Tang et a., arXiv:hep-ph/0604078
Rock type	Inishi rock assuming the same rock type with SK
Typical rock density	2.70 g/cm^{-3}

- Elevation data
  "ALOS World 3D-30m" provided by JAXA
- HKK position in white paper
  35°43'00" N
  128°31'28" E
- Altitude of HKK
  264 m (820 m overburden)
  84 m (1,000 m overburden)

(I.Shimizu)

Digital Elevation Data : Mt. Bohyun

Elevation data (**30 m mesh**)
around peak of Mt. Bohyun



Peak 1124 m

simulation condition

Surface muon flux	Modified Gaisser model A. Tang et a., arXiv:hep-ph/0604078
Rock type	Inishi rock assuming the same rock type with SK
Typical rock density	2.70 g/cm^{-3}

- Elevation data
  "ALOS World 3D-30m" provided by JAXA
- HKK position in white paper
  36°09'47" N
  128°58'26" E
- Altitude of HKK
  304 m (820 m overburden)
  124 m (1,000 m overburden)

Muon Flux and Spallation

- Muon flux and spallation simulations are performed to estimate the rate of spallation products at HK, comparing to SK.

MUSIC (MUon SImulation Code) for muon flux simulation

3D MC tool dedicated to muon transportation in matter

(1) Ionization (Bethe-Bloch formula) (2) Bremsstrahlung
(3) e-/e+ pair production (4) Muon-nucleus inelastic scattering

V.A. Kudryavtsev, arXiv:0810.4635

FLUKA for spallation simulation (Isotope yield)

General purpose MC tool for particle transport and interactions.
Spallation MC by FLUKA using muon energy spectrum at HK/SK.

<u>Spallation Rate at HK</u>

$$\text{Rate (HK)} = \underbrace{\text{Rate (SK)}}_{\text{Data}} \times \underbrace{\frac{\Phi(\text{HK})}{\Phi(\text{SK})}}_{\text{MC (MUSIC)}} \times \underbrace{\frac{Y(\text{HK})}{Y(\text{SK})}}_{\text{MC (FLUKA)}}$$

Φ: muon flux ($cm^{-2}s^{-1}$) **Y: isotope yield (/μ/m)**
(muon energy dependent)

Summary of muon/spallation rates

820 m overburden

Ratio of total muon flux ($\text{HKK}_{\text{Bisul}}$ / SK) = **2.47 ± 0.49**

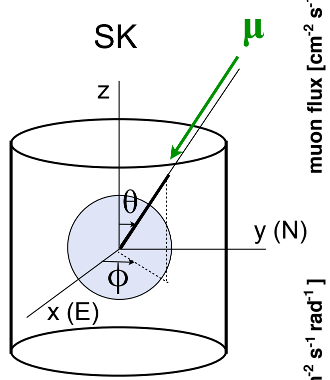
Ratio of rate (^{16}N) ($\text{HKK}_{\text{Bisul}}$ / SK) = **1.99 ± 0.44**

1,000 m overburden

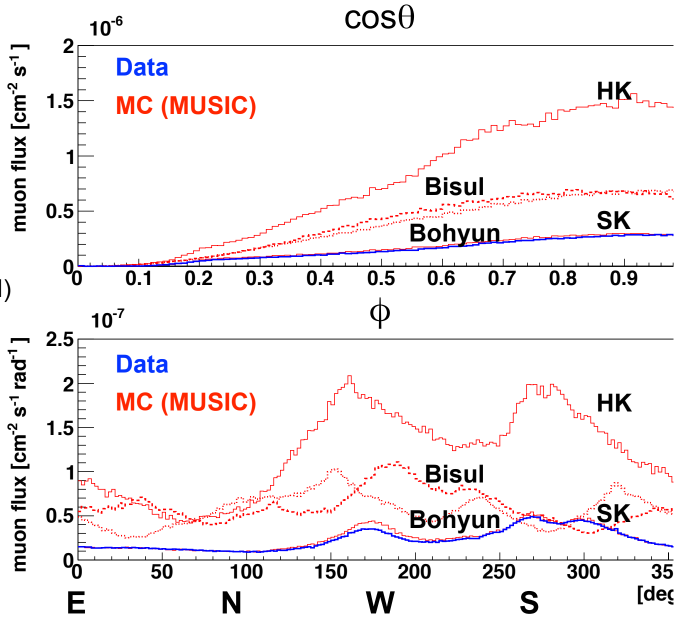
Ratio of total muon flux ($\text{HKK}_{\text{Bisul}}$ / SK) = **1.03 ± 0.21**

Ratio of rate (^{16}N) ($\text{HKK}_{\text{Bisul}}$ / SK) = **1.03 ± 0.21**

Comparison of Muon Flux **HKK 820 m overburden**

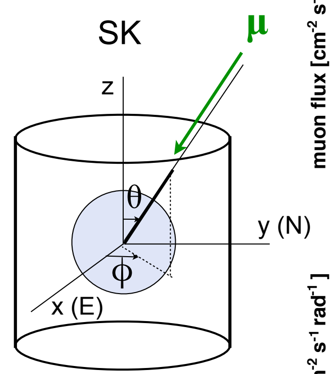


muon flux measurement
with 12 day data
in spherical volume
(R = 10 m)

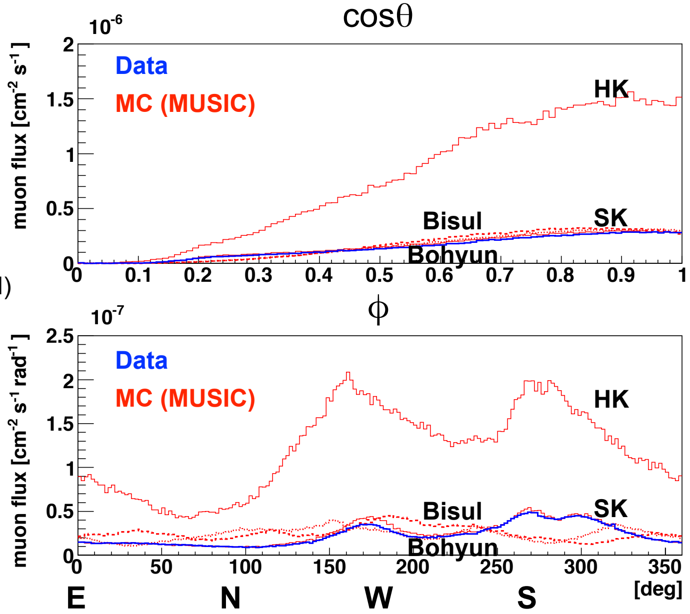


Ratio of total muon flux Bisul / SK = **2.47 ± 0.49** Bohyun / SK = **2.32 ± 0.46** HK / SK = **4.90 ± 0.98**

Comparison of Muon Flux **HKK 1,000 m overburden**



muon flux measurement
with 12 day data
in spherical volume
(R = 10 m)



Ratio of total muon flux Bisul / SK = **1.03 ± 0.21** Bohyun / SK = **0.97 ± 0.19** HK / SK = **4.90 ± 0.98**

Remaining spallation for solar ν

- We apply "improved spallation cuts," keeping the signal efficiency of 80%.
- The remaining spallation BG will be, compared to SK-II case (with current cut)
  - 20% for 1000km overburden
  - 80% for 820m overburden
- The improved spallation cut will also be applied to SK solar analysis in near future.
- We need a help to translate these values to physics sensitivity, for Korean site.

flux/location	SK-II 1000m	$\mu \times 1$ 1000m	$\mu \times 2$ Mozumi Hakamagoshi	$\mu \times 2.5$ 820m	$\mu \times 5$ Tochibora
Signal Efficiency	80%				
	Current (solar) spallation cut	Improved (Relic) Spallation cut			
Spallation reduction efficiency	6%	1.2%	2.1%	2.3%	3.9%
Amount of spallation product	×1	×1	×2	×2	×4
Spallation BG left (comparing to amount before spallation cut)	~6%	~1.2%	~4%	~4.6%	~16%

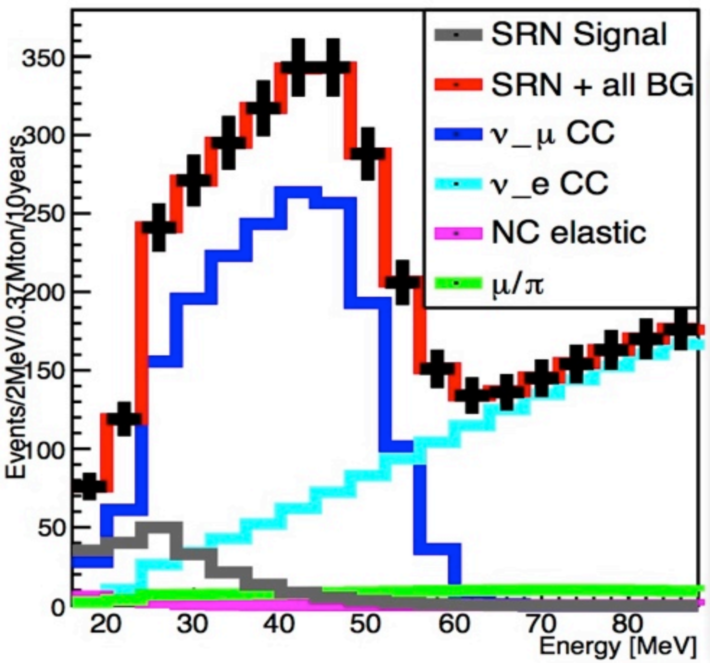
~80%

~20%

Signal efficiency for SRN search

- With a deeper site, we can keep better signal efficiency at lower energy, where the supernova relic neutrino has larger flux.
  - Spallation cut is set to kill all spallation product.
- With 1000m overburden, the amount of signal is expected to be ~ ×2 of that for Tochibora.
- Estimation of the signal amount is ongoing.

Middle angle (38-50°)

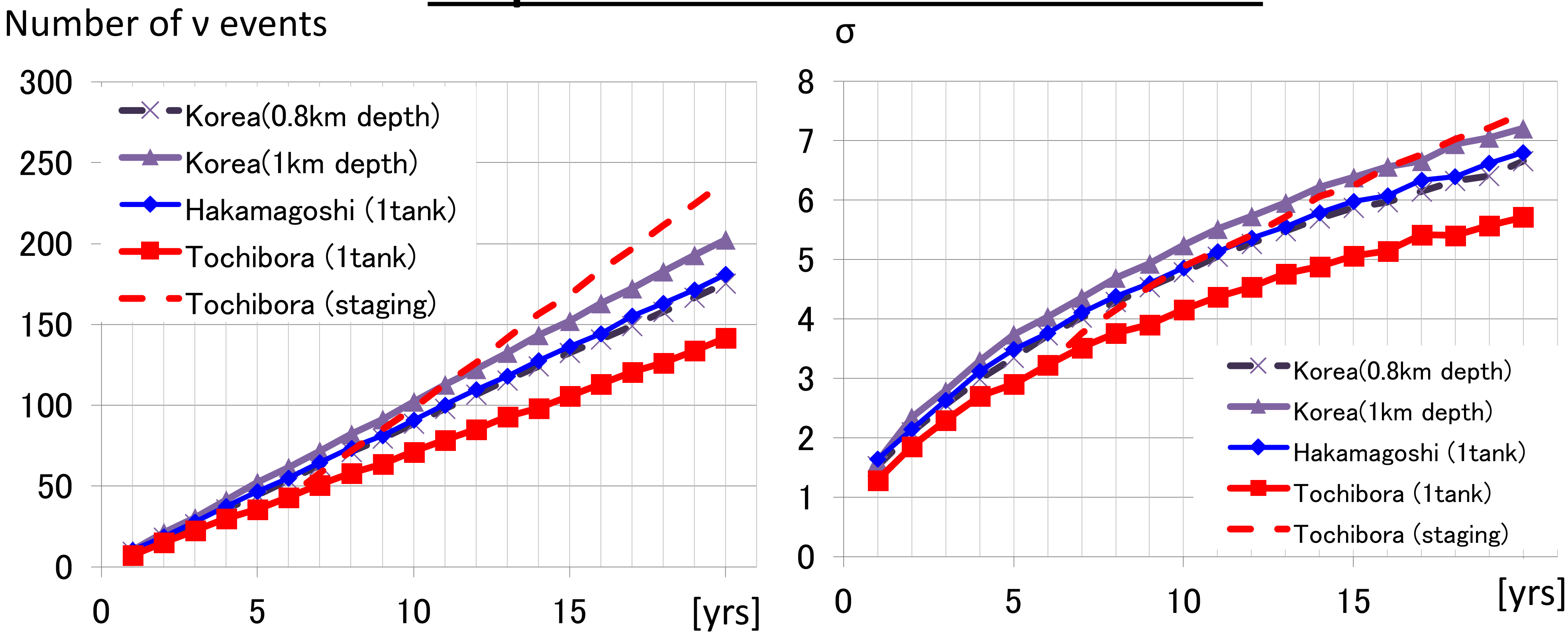


Staging 20years

- **Spallation cut condition is set to be :**
  - Negligible Spallation background in search energy window.

Signal Eff. after spacut	μ ×1 1000m	μ ×2 Mozumi Hakamagoshi	μ ×2.5 820m	μ ×5 Tochibora
~20MeV	79%	62%	56%	29%
20~26MeV	90%	77%	75%	54%

Supernova Relic Neutrino



- Korea 1km : ~100 events/tank/10y, ~5.2 σ non-0 significance.
- Staging : ~98 events/2tank/10y, ~4.8 σ
- Korea 0.8km & Hakamagoshi : ~90 events/tank/10y, ~4.8 σ.
- Tochibora : ~71 events/tank/10y, ~4.2 σ

  - 70% n-tag efficiency is assumed.

- Lower spallation BG is quite important for SRN!! (and solar!).

Summary

- Larger overburden can improve the sensitivity on low energy physics with less muon spallation backgrounds.
  - i.e. solar neutrino analysis and supernova relic neutrino search.

- **Simulation of muon flux**
- **Estimation of background reduction for solar ν**
- **Estimation of signal efficiency for SRN**

  are done.

- **Your contributions for low energy study (physics, detector performance) are needed and welcome.**