

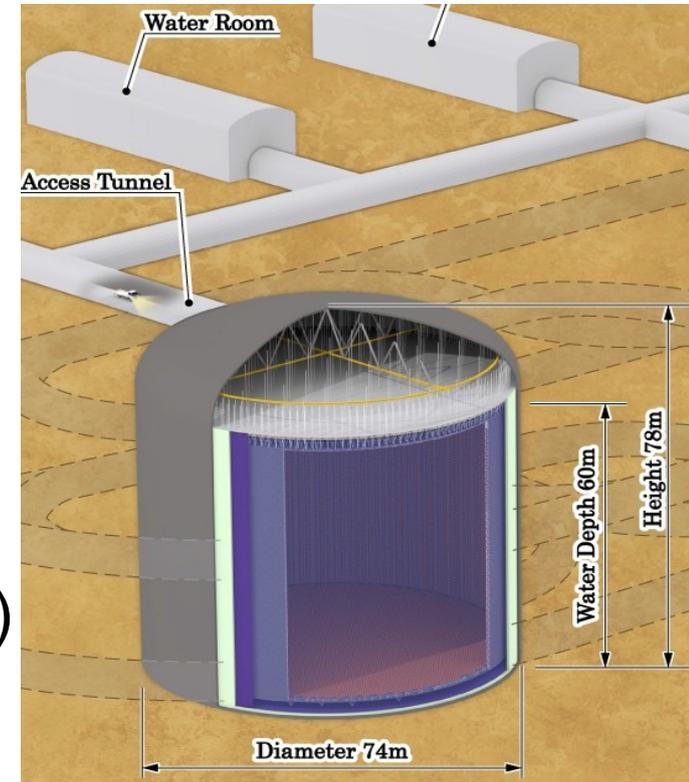
# **Supernova Relic Neutrino Sensitivity Study with 2<sup>nd</sup> Hyper-Kamiokande in Korea**

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# Hyper-Kamiokande

- Hyper-Kamiokande (HK) is a future water-Cherenkov neutrino detector.
- From beam neutrino ( $\delta_{cp}$  measurement, neutrino mass ordering) to astrophysics (SR & SRN...)



	SK	HK (for 1 tank)
No. of PMTs (ID)	11,129	40,000
Photocoverage	40%	40%
Volume / FV	50 kt / 22.5 kt	260 kt / 187 kt

# Benefits of 2<sup>nd</sup> Detector in Korea

- HK in Korea has deeper overburden ( $\sim 1$  km) than HK in Japan ( $\sim 650$  m) $\rightarrow$  less background expected.
- For the SRN, less background muon flux and its spallation isotope yield is expected.
- Geographical separation $\rightarrow$  pointing precision of supernova burst will be improved.

# Supernova Relic Neutrino (SRN) Sensitivity Simulation

- SRN: Diffuse flux of neutrinos emitted by all supernovae since the beginning of the universe.
- Can be detected from IBD. ( $p + \bar{\nu}_e \rightarrow n + e^+$ )
  - 1) Most important background: Cosmic muon flux.
  - 2) Spallation isotope also need to be simulated.
  - 3) Signal efficiency cut is calculated.  
→ SRN sensitivity.

# Korean Candidate Sites

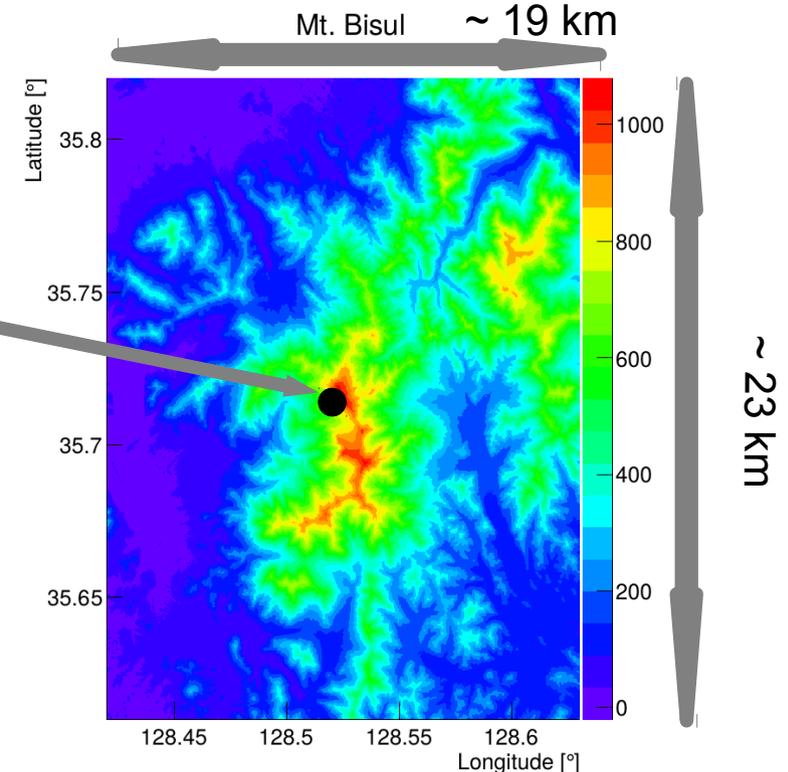
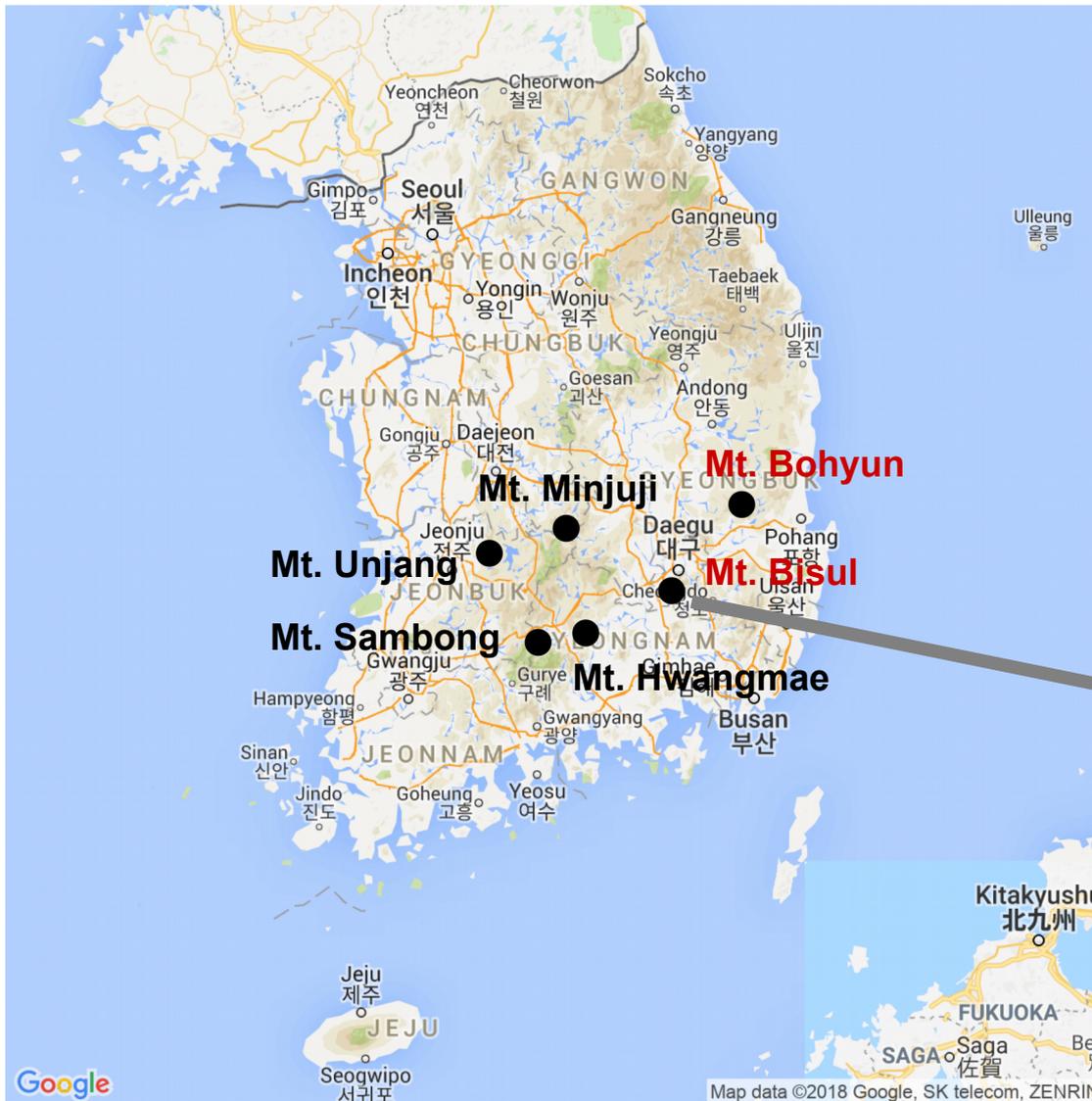
- 6 Korean candidate sites are listed here...

	Mt. Bisul	Mt. Bohyun	Mt. Hwangmae	Mt. Minjuji	Mt. Sambong	Mt. unjang
Latitude	35°43'00" N	36°09'47" N	35°29'47" N	36°02'24" N	35°26'52" N	35°54'39" N
Longitude	128°31'28" E	128°58'26" E	127°58'28" E	127°50'57" E	127°40'10" E	127°21'26" E
Height	1084 m	1124 m	1113 m	1242 m	1186 m	1125 m
1000 m depth	84 m	124 m	113 m	242 m	186 m	125 m

# Korean Candidate Sites

- Extract the geographic information by using QGIS

(Quantum Geographic Information System)

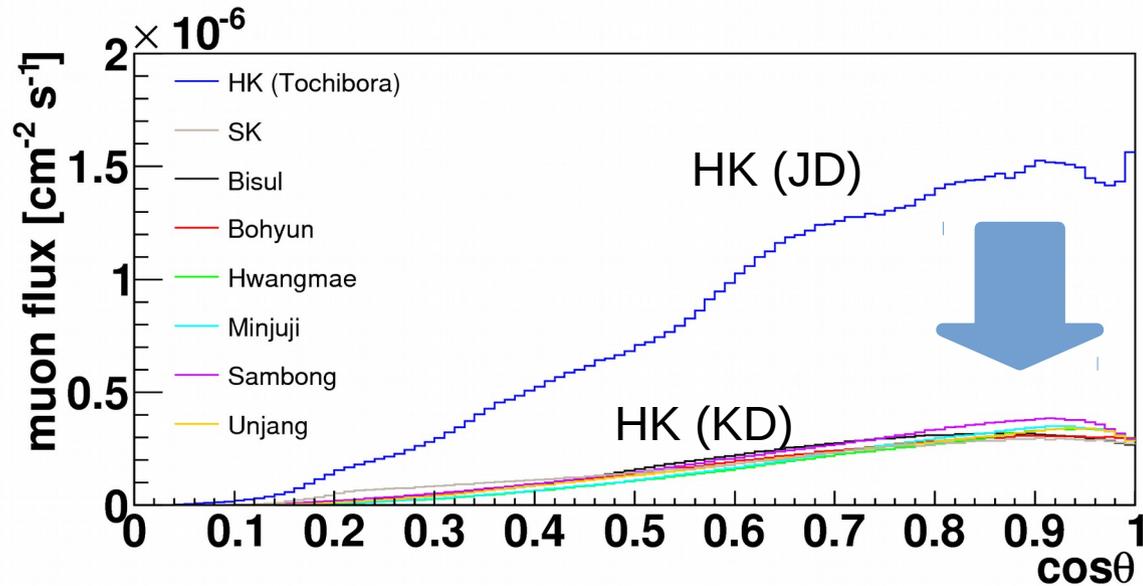


- Elevation data: “ALOS World 3D-30m” provided by JAXA. (30m mesh)

# Background Muon Flux

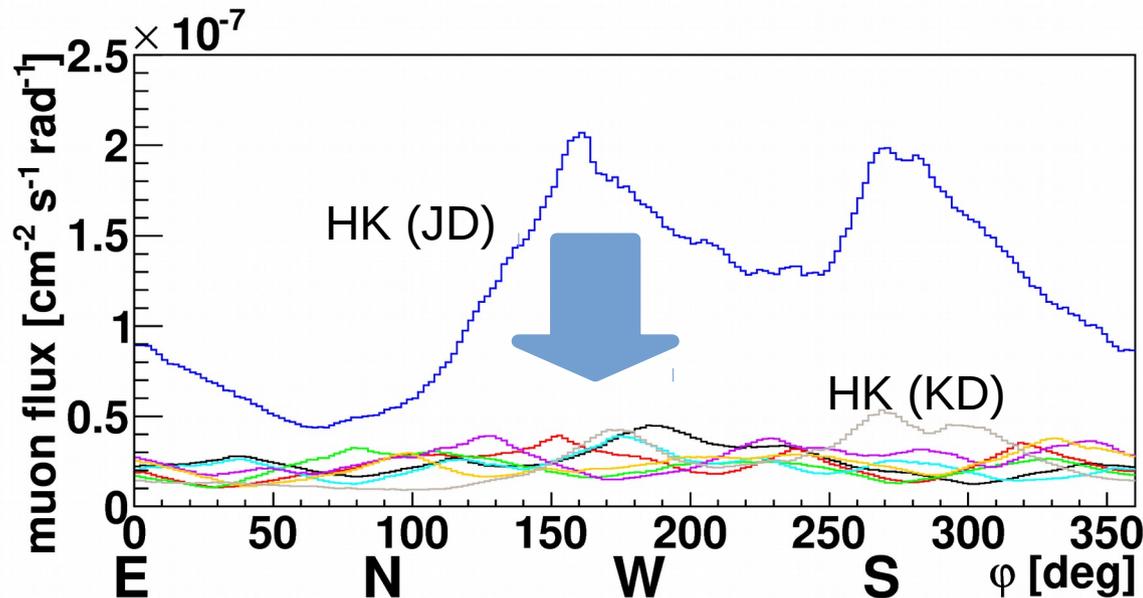
- I simulated the background muon flux for 6 Korean candidate sites, which is the main background of SRN events by using MUSIC.
- I assume
  - Rock density:  $2.70\text{g/cm}^3$ .
  - Overburden of all Korean candidate sites: 1 km.
  - Overburden of HK JD: 650 m.

# Background Muon Flux



Above:  $\cos\theta$  (Zenith angle) distribution

Below:  $\varphi$  (azimuth) distribution



**Simulated background muon flux for KD is much less than JD. ( $\sim 1/5$ )**

# Background Muon Flux

Candidate Sites	Total Muon Flux ( $10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$ )	Mean Energy (GeV)	Flux ratio Sites/SK (Sys. Error)
Mt. Bisul	1.57	253.7	1.04±0.21
Mt. Bohyun	1.47	255.9	0.97±0.19
Mt. Hwangmae	1.35	254.8	0.89±0.18
Mt. Minjuji	1.41	253.3	0.93±0.19
Mt. Sambong	1.67	251.3	1.11±0.22
Mt. Unjang	1.46	256.3	0.96±0.19
Tochibora (JD)	7.52	202.2	4.97±0.99

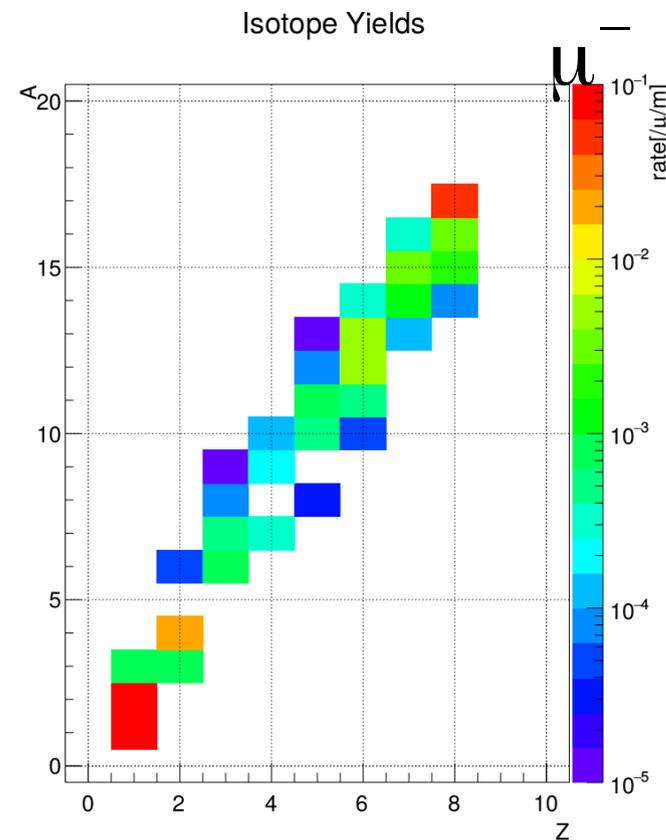
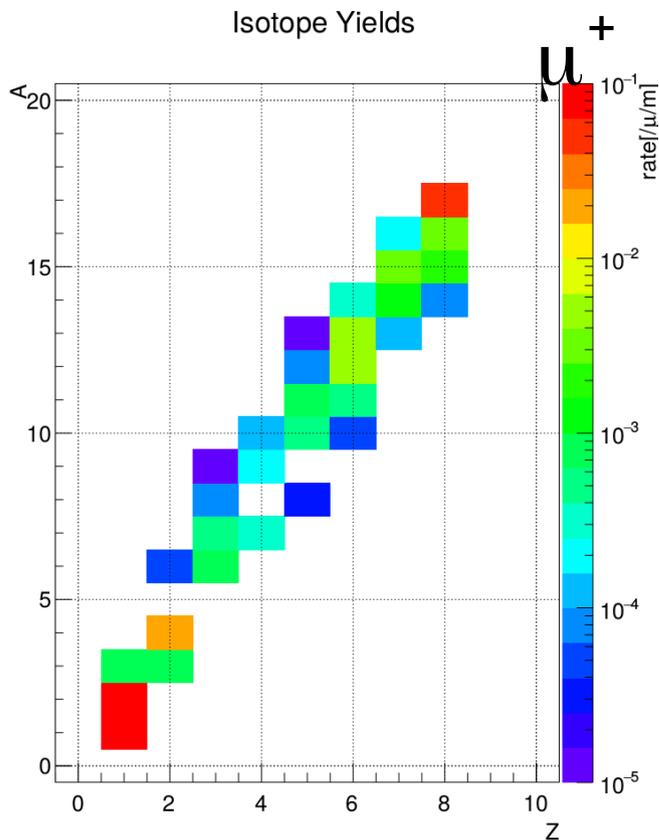
# Muon Spallation Isotope

- Spallation isotopes from cosmic muon mimic real SRN signal. → Spallation isotope simulation is needed.
- Muon spallation isotope yield is calculated by FLUKA.
- Assuming  $\mu^+/\mu^- \sim 1.3$ . (See *arXiv: 1005.5332*)

# Muon Spallation Isotope

- From spallation isotope yield,

HK (JD)



$$\text{Rate of isotope (HK)} = \text{Rate of isotope (SK)} \times \frac{\Phi(\text{HK})}{\Phi(\text{SK})} \times \frac{Y(\text{HK})}{Y(\text{SK})}$$

(  $\Phi$ : Muon flux ( $\text{cm}^{-2} \text{s}^{-1}$ ),  $Y$ : Muon Spallation isotope yields ( $/m/\mu$ ). )

# Muon Spallation Isotope

Sites are indicated by colors.

Blue: HK(Tochibora)

Black: Mt. Bisul

Red: Mt. Bohyun

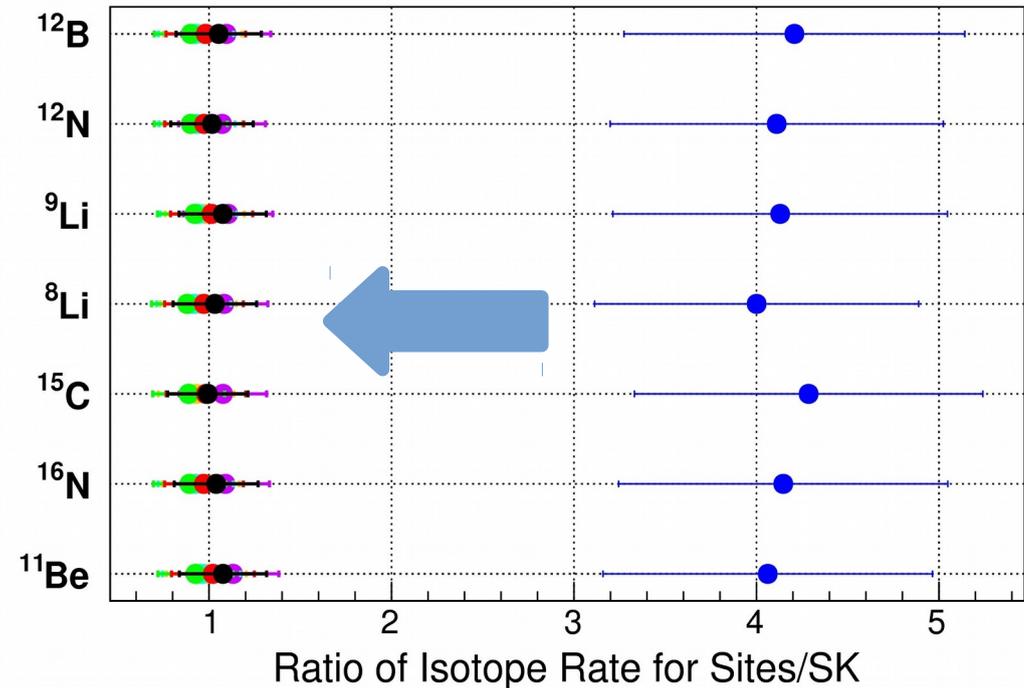
Green: Mt. Hwangmae

Cyan: Mt. Minjuji

Violet: Mt. Sambong

Orange: Mt. Unjang

(Include stat.+sys. Error.)



Amount of muon spallation isotope for **HK JD is ~4 times** of SK, while that of **Korean sites are almost same.**

# Signal Efficiency of Spallation Cut

Based on Kirk Bays et al., arXiv: 1111.5031

SRN flux: LMA, arXiv:astro-ph/0202450

- Signal Efficiency of spallation cut is calculated.  
( $\mu$ : Background cosmic muon flux at the SK)

Signal Efficiency	$\mu \times 1$	$\times 2$	$\times 3$	$\times 4$	$\times 5$	$\times 7$	$\times 10$
17.5 – 20 MeV	78.7 %	62.0 %	49.9 %	38.7 %	29.1 %	17.4 %	8.9 %
20 – 26 MeV	89.6 %	77.4 %	72.6 %	67.0 %	54.7 %	42.5 %	34.0 %

Signal efficiency for different muon flux.

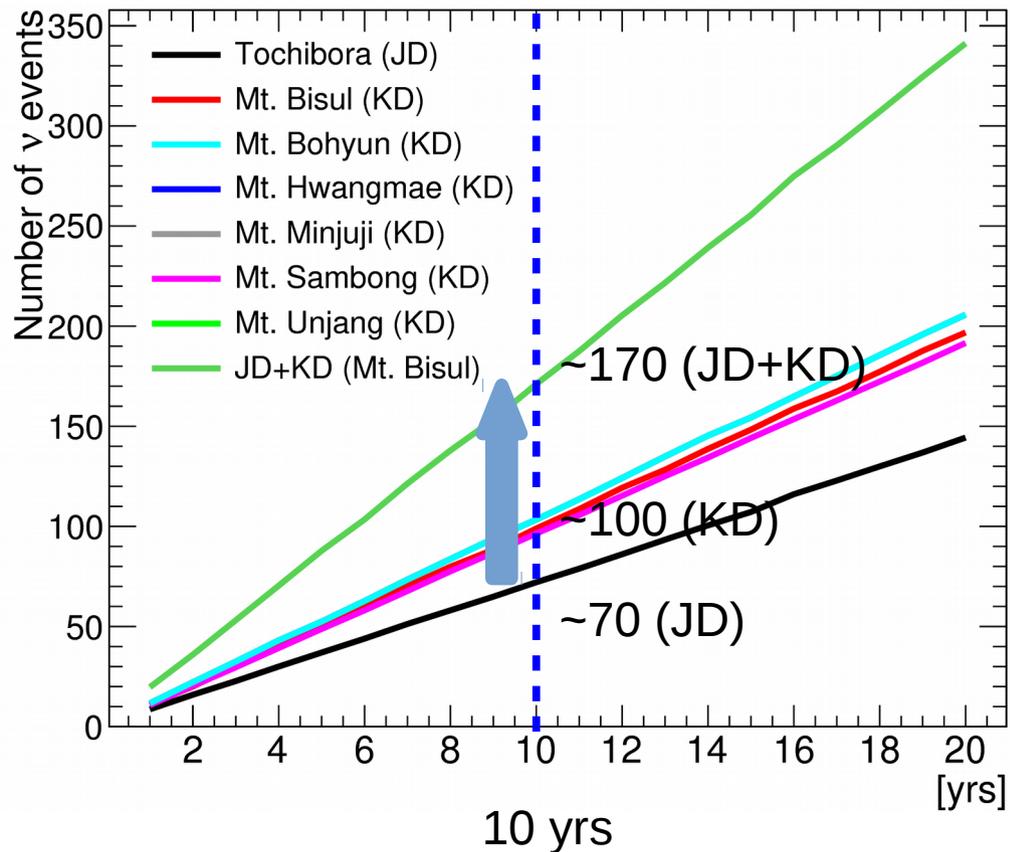
Signal Efficiency	JD	Mt. Bisul	Mt. Bohyun	Mt. Hwangmae	Mt. Minjuji	Mt. Sambong	Mt. Unjang
17.5 – 20 MeV	29.1 %	70.9 %	78.9 %	78.9 %	78.9 %	68.4 %	78.9 %
20 – 26 MeV	54.7 %	84.9 %	89.6 %	89.6 %	89.6 %	81.1 %	89.6 %

Signal efficiency for Korean candidate sites+Tochibora.

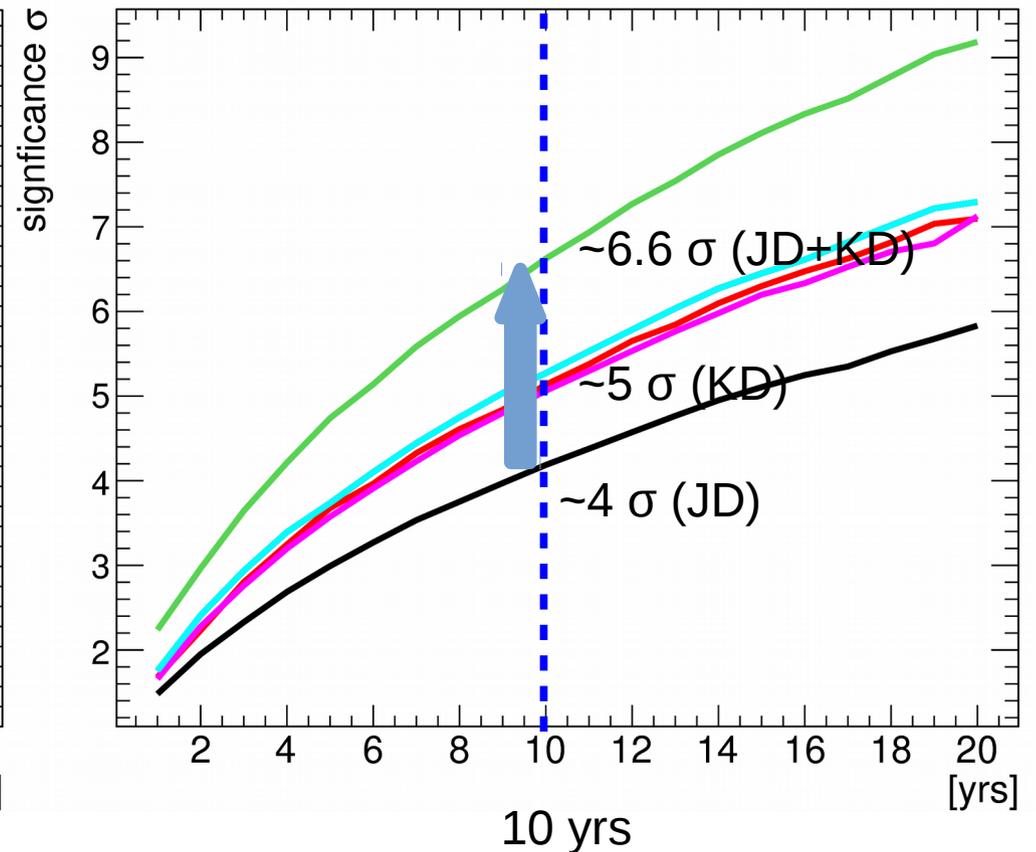
# SRN Sensitivity

- Expected SRN & Significance for HKK & HK JD.

Number of SRN Events



Significance of SRN Detection



# SRN Sensitivity

- JD only:  $\sim 72$  events and  $\sim 4.2\sigma$  for 10 years detection.

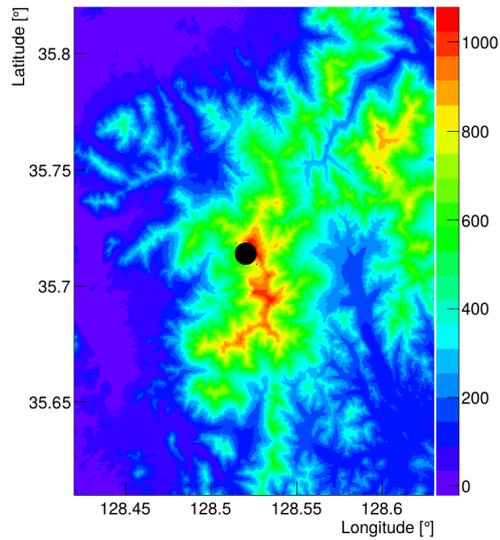
Location	No. of Events (/10yrs)	Significance $\sigma$ (/10yrs)	No. of Events + JD (/10yrs)	Significance $\sigma$ +JD (/10yrs)
Mt. Bisul	$\sim 99$	$\sim 5.1$	$\sim 171$	$\sim 6.6$
Mt. Bohyun	$\sim 103$	$\sim 5.1$	$\sim 175$	$\sim 6.7$
Mt. Hwangmae	$\sim 103$	$\sim 5.3$	$\sim 175$	$\sim 6.7$
Mt. Minjuji	$\sim 103$	$\sim 5.3$	$\sim 175$	$\sim 6.7$
Mt. Sambong	$\sim 96$	$\sim 5.1$	$\sim 169$	$\sim 6.6$
Mt. Unjang	$\sim 103$	$\sim 5.3$	$\sim 175$	$\sim 6.7$

# Summary

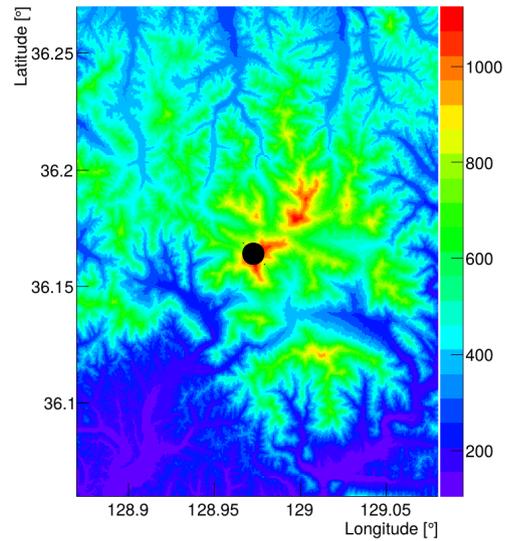
- All HK KD candidate sites have comparable amount of muon flux & spallation isotope with SK and much less than HK JD.
- SRN sensitivity for Korean detector is much improved than that of JD:  
Events:  $\sim 72$  (JD)  $\rightarrow$   $\sim 171$  (JD+KD)  
Significance:  $\sim 4.2 \sigma$  (JD)  $\rightarrow$   $\sim 6.6 \sigma$  (JD+KD)  
for 10 yrs of detection.

# Back Up: All Korean Candidate Sites-Elevation Plot

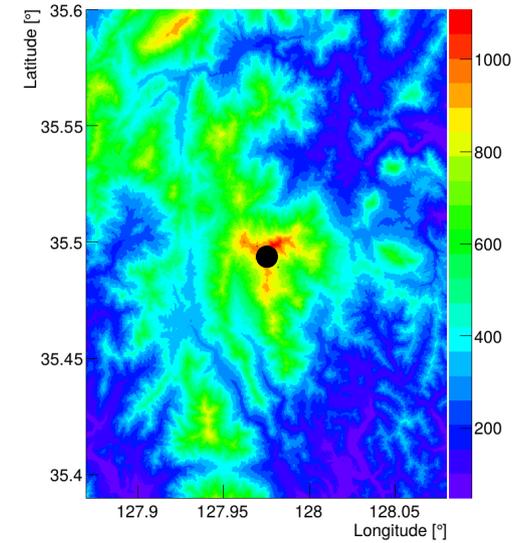
Mt. Bisul



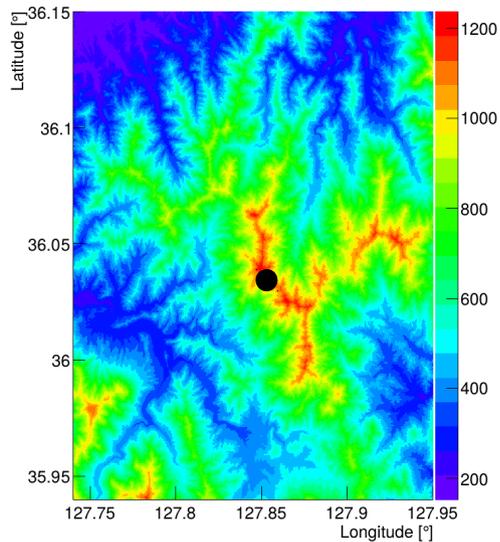
Mt. Bohyun



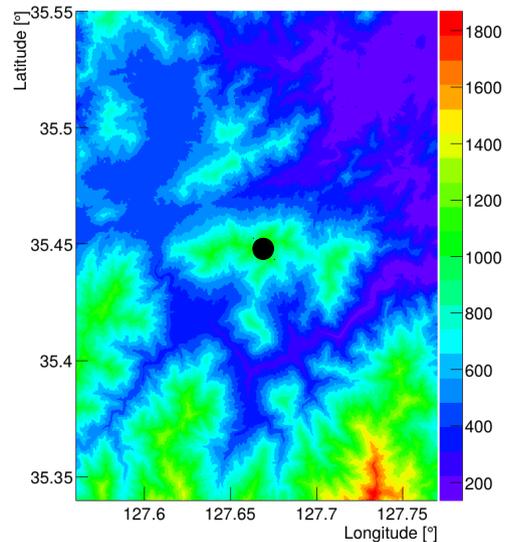
Mt. Hwangmae



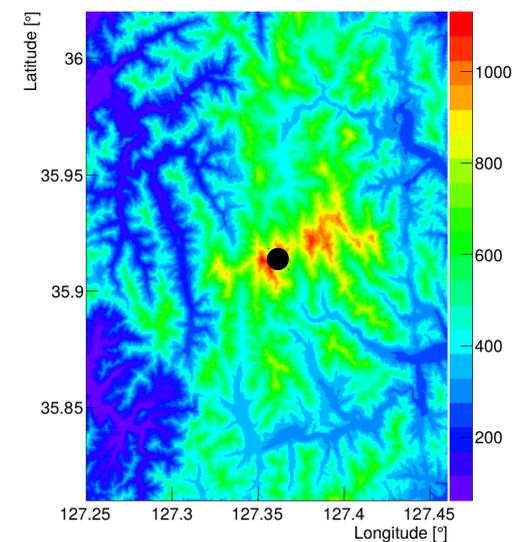
Mt. Minjuji



Mt. Sambong

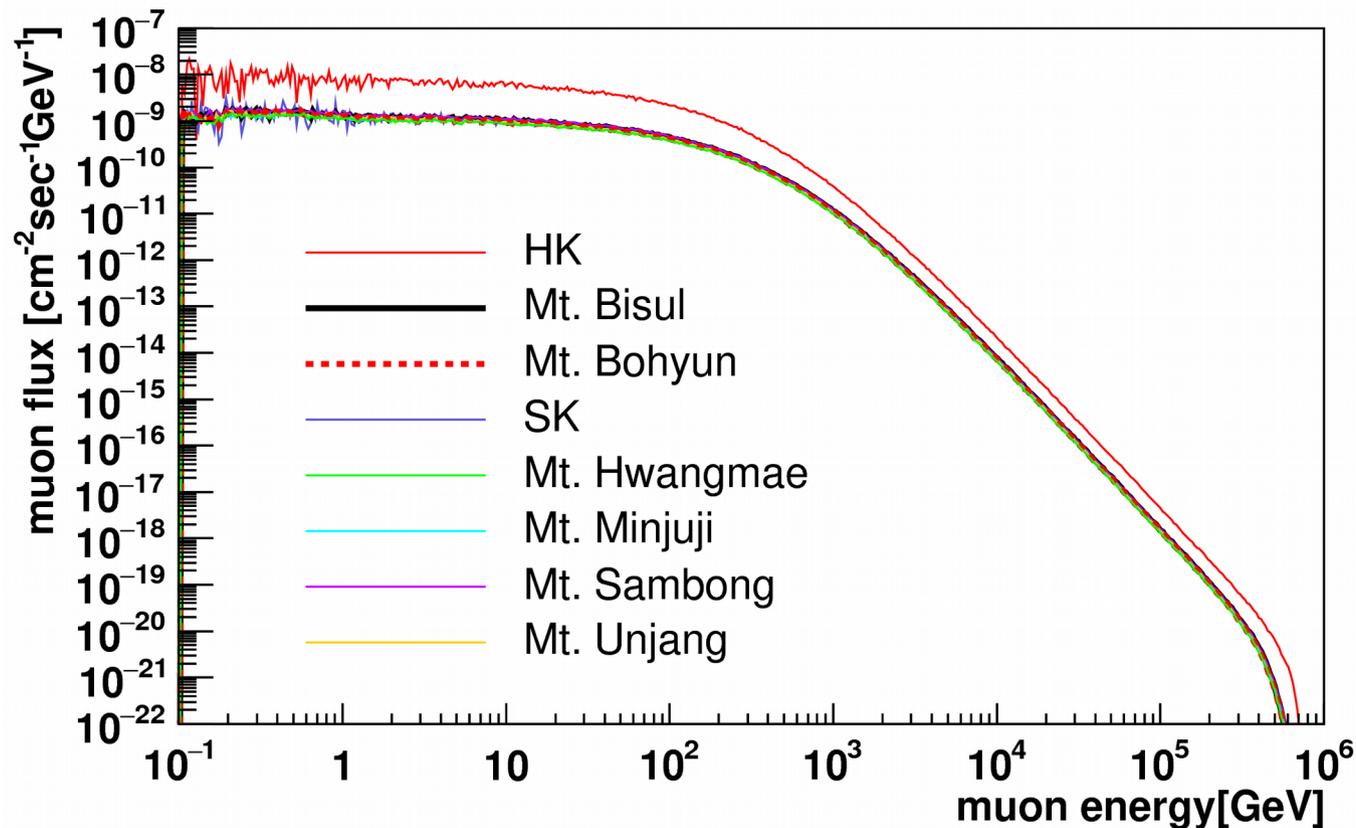


Mt. Unjang



# Back Up: Background Muon Flux Energy Spectrum

- Calculated from MUSIC.
- This plot used for the spallation isotope yield calculation.



# Back Up: Ratio of Isotope rate for <sup>19</sup>T2HKK

	Ratio of isotope rate simulated by FLUKA (Sites/SK)		
	HK(JD)	Mt. Bisul	Mt. Bohyun
<sup>12</sup> B	4.208 ± 0.934	1.053 ± 0.234	0.982 ± 0.218
<sup>12</sup> N	4.111 ± 0.913	1.016 ± 0.226	0.973 ± 0.216
<sup>9</sup> Li	4.130 ± 0.917	1.075 ± 0.239	1.014 ± 0.225
<sup>8</sup> Li	4.001 ± 0.888	1.032 ± 0.229	0.972 ± 0.216
<sup>15</sup> C	4.286 ± 0.955	0.993 ± 0.220	0.983 ± 0.218
<sup>16</sup> N	4.147 ± 0.920	1.039 ± 0.230	0.972 ± 0.216
<sup>11</sup> Be	4.062 ± 0.903	1.076 ± 0.239	1.021 ± 0.227

# Back Up: Ratio of Isotope rate for <sup>20</sup>T2HKK

- Mt. Hwangmae/Minjuji/Sambong/Unjang

	Ratio of isotope rate simulated by FLUKA (Sites/SK)			
	Mt. Hwangmae	Mt. Minjuji	Mt. Sambong	Mt. Unjang
<sup>12</sup> B	0.900 ± 0.200	0.928 ± 0.206	1.095 ± 0.243	0.966 ± 0.214
<sup>12</sup> N	0.900 ± 0.200	0.934 ± 0.208	1.071 ± 0.238	0.969 ± 0.215
<sup>9</sup> Li	0.921 ± 0.204	0.941 ± 0.209	1.104 ± 0.245	0.976 ± 0.217
<sup>8</sup> Li	0.880 ± 0.195	0.916 ± 0.203	1.082 ± 0.240	0.940 ± 0.209
<sup>15</sup> C	0.888 ± 0.197	0.888 ± 0.197	1.076 ± 0.239	0.929 ± 0.207
<sup>16</sup> N	0.893 ± 0.198	0.927 ± 0.206	1.089 ± 0.242	0.055 ± 0.212
<sup>11</sup> Be	0.926 ± 0.206	0.959 ± 0.213	1.131 ± 0.251	0.985 ± 0.219