Supernova Relic Neutrino Search with Hyper Kamiokande

Takatomi **Yano** (Okayama Univ.)
for HK-Astro WG

27th Jan. 2014
4th Open Meeting for the Hyper-Kamiokande meeting

Motivation & Contents

Motivation

- Spallation is the dominant background source in 10 – 20 MeV.
- The amount of muon flux / spallation product and the effect on SRN search is studied for HK candidate sites.

Contents

1. Muon Flux at Mozumi Site

   studied by I. Shimizu (Tohoku Univ.)

2. SRN Search with Hyper-Kamiokande

   studied by T. Yano (Okayama Univ.)

Muon Flux : Status So far

- Muon flux was studied with MUSIC, for correct HK position at Tochibora.
- Spallation production was also studied with FLUKA.

Muon Flux : ×4.9± 0.98 of current SK
Spallation : ×4 ± 1 of current SK

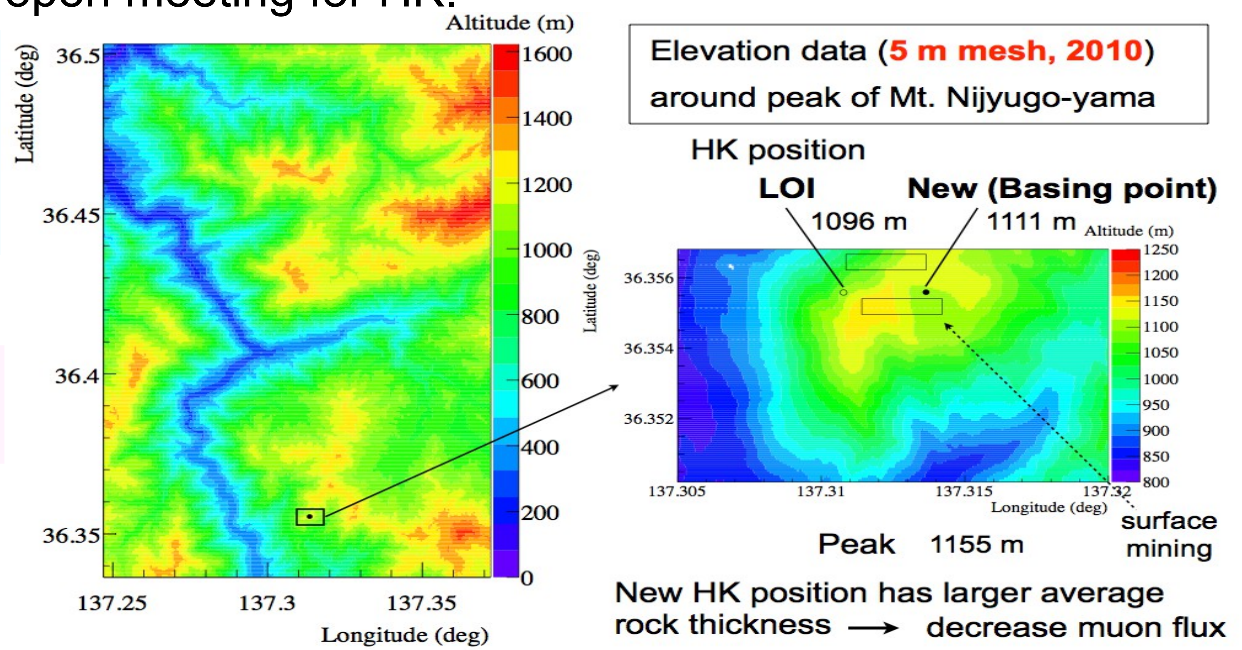
I. Shimizu, 3rd open meeting for HK.

HK Position	LOI	New
World geographical coordinate system	36°21’20.078” N 137°18’38.798” E	36°21’20.105” N 137°18’49.137” E
Altitude	**1096 m**	**1111 m**

*Altitude of HK is 508 m

Mountain Shape	LOI	New
Digital Elevation Data	**50 m mesh**	**5 m mesh**

Elevation data (**5 m mesh, 2010**)
around peak of Mt. Nijyugo-yama

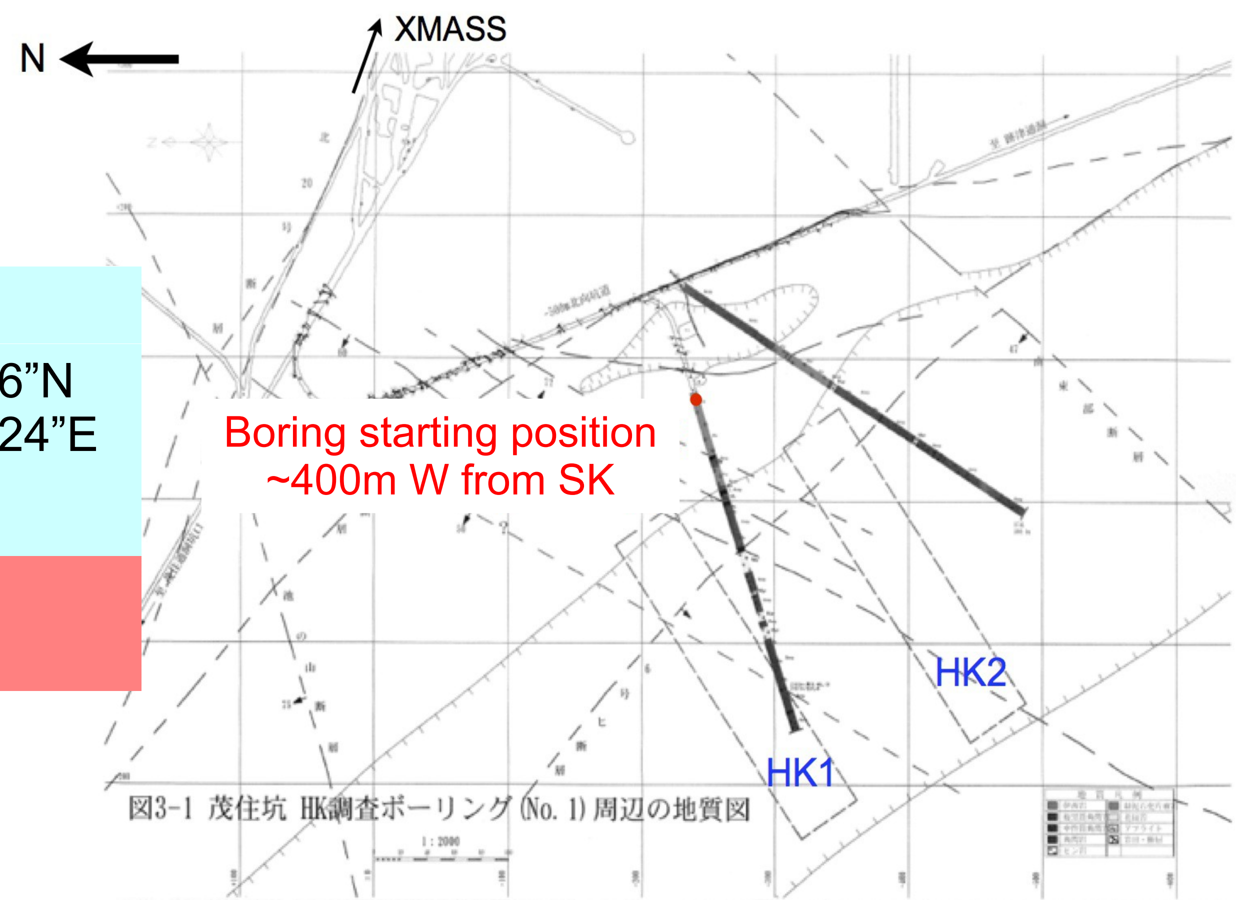


New HK position has larger average rock thickness → decrease muon flux

Calculation of Muon Flux at Mozumi

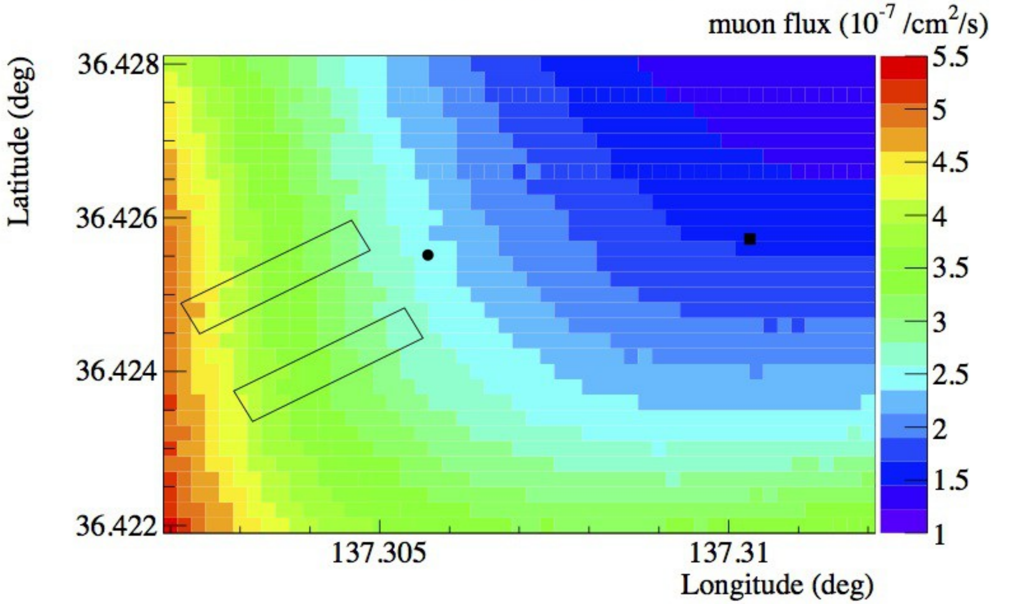
- A boring test was done at Mozumi site for HK.
- Boring starting position is ~400m west of SK.
- HK center position is read from the blue print for the boring test.

HK center position	Mozumi
World geographical Coodinate system	36°25'28.7796"N 137°18'13.9824"E
Altitude of HK	354.466m
Digital Elevation Data (Mountain Shape)	**50m mesh**

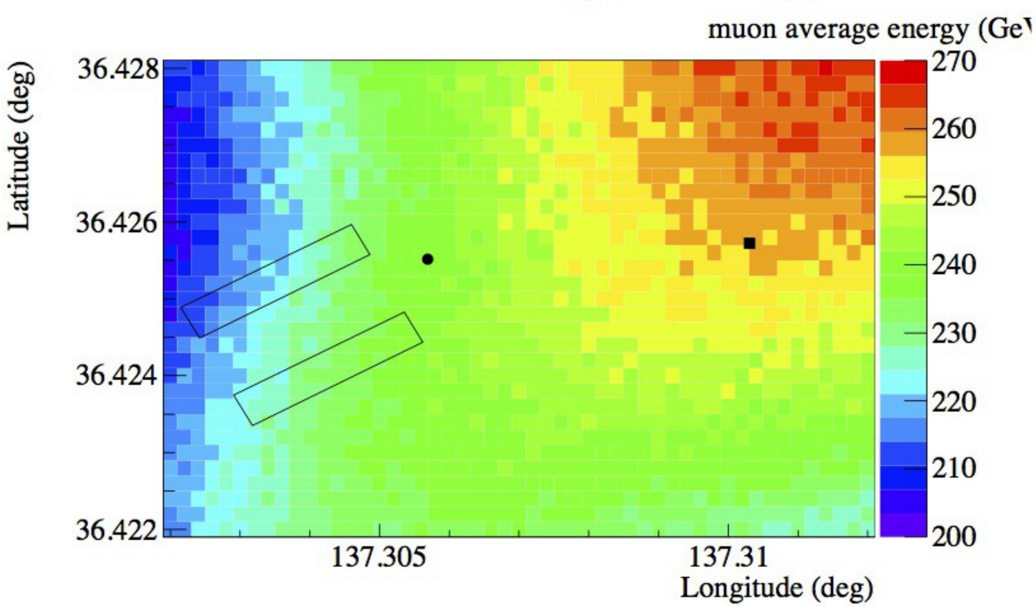


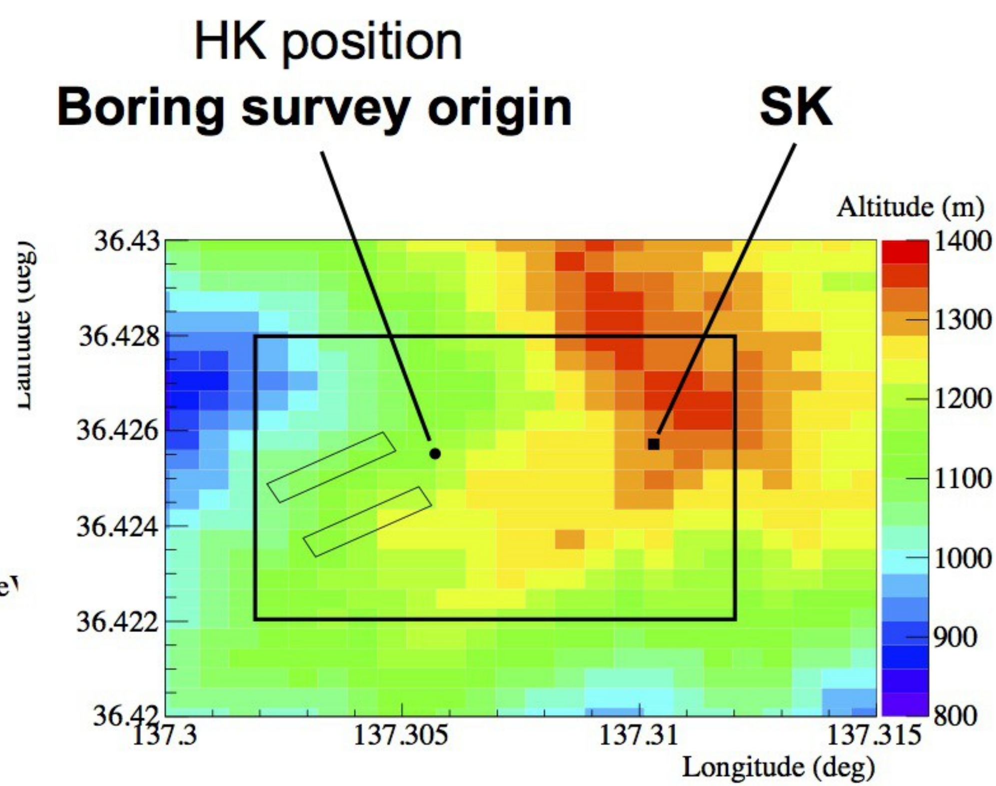
Muon Simulation at Mozumi

muon flux



muon average energy



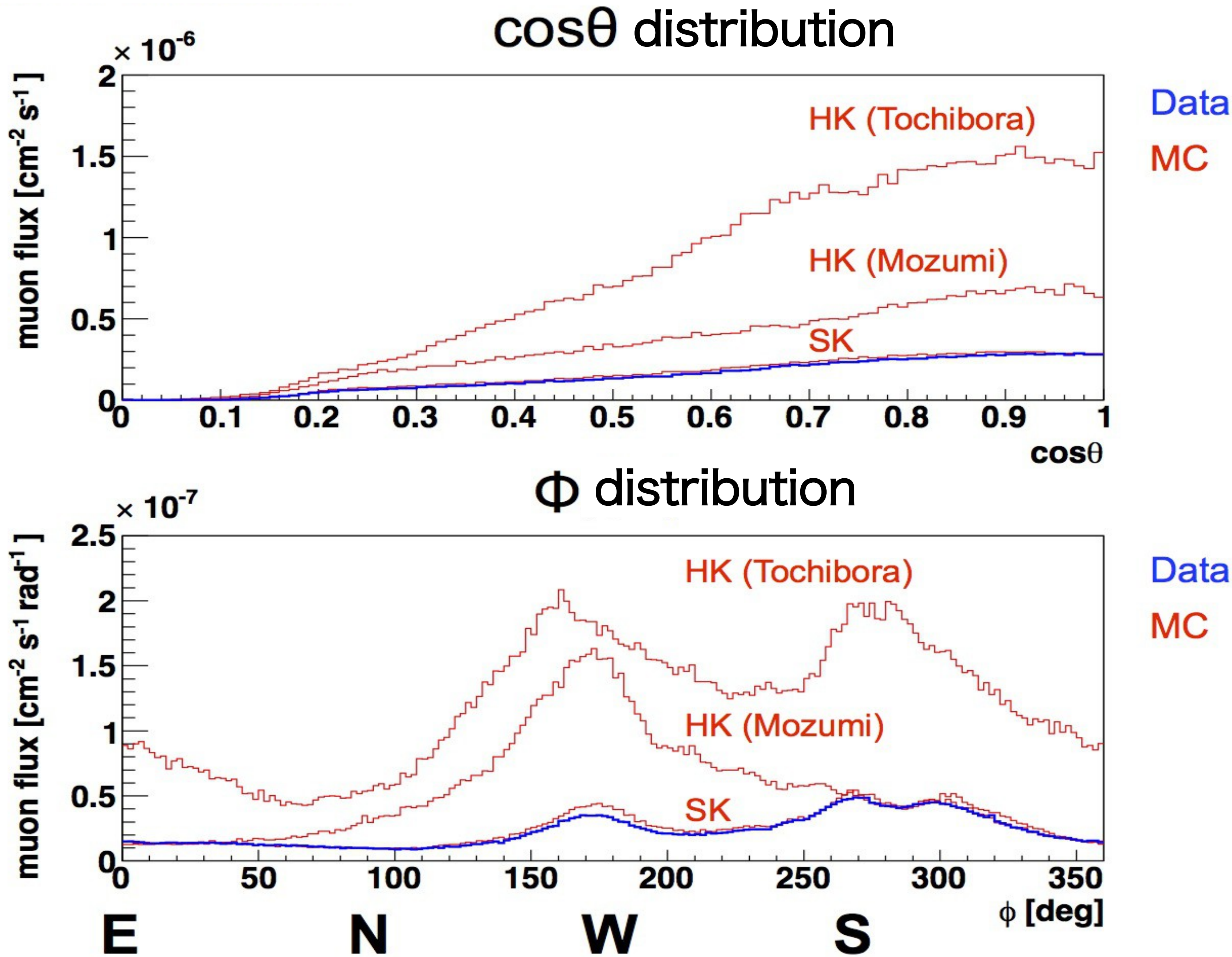


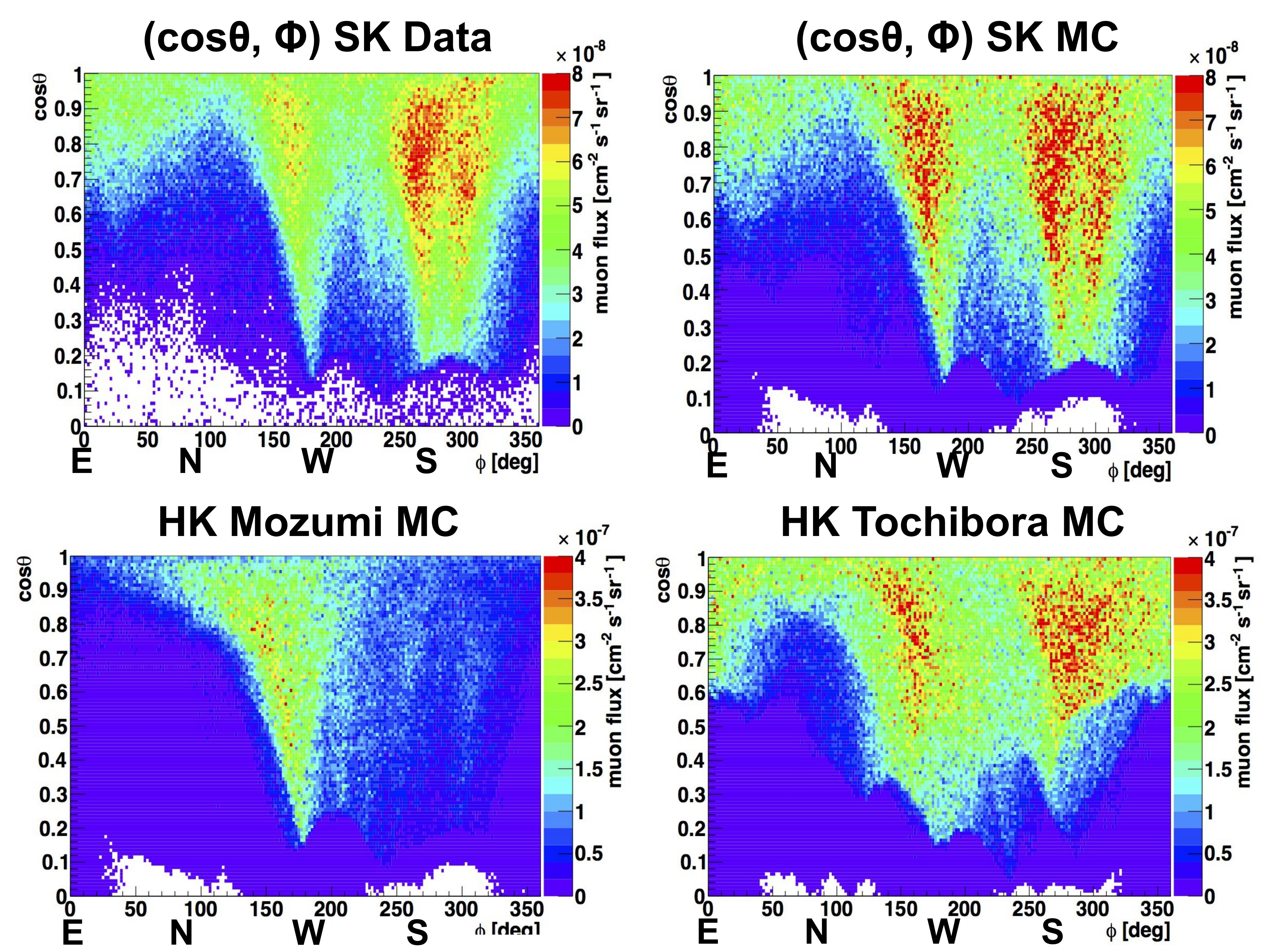
shallower in the west and south

↓

higher flux and lower energy

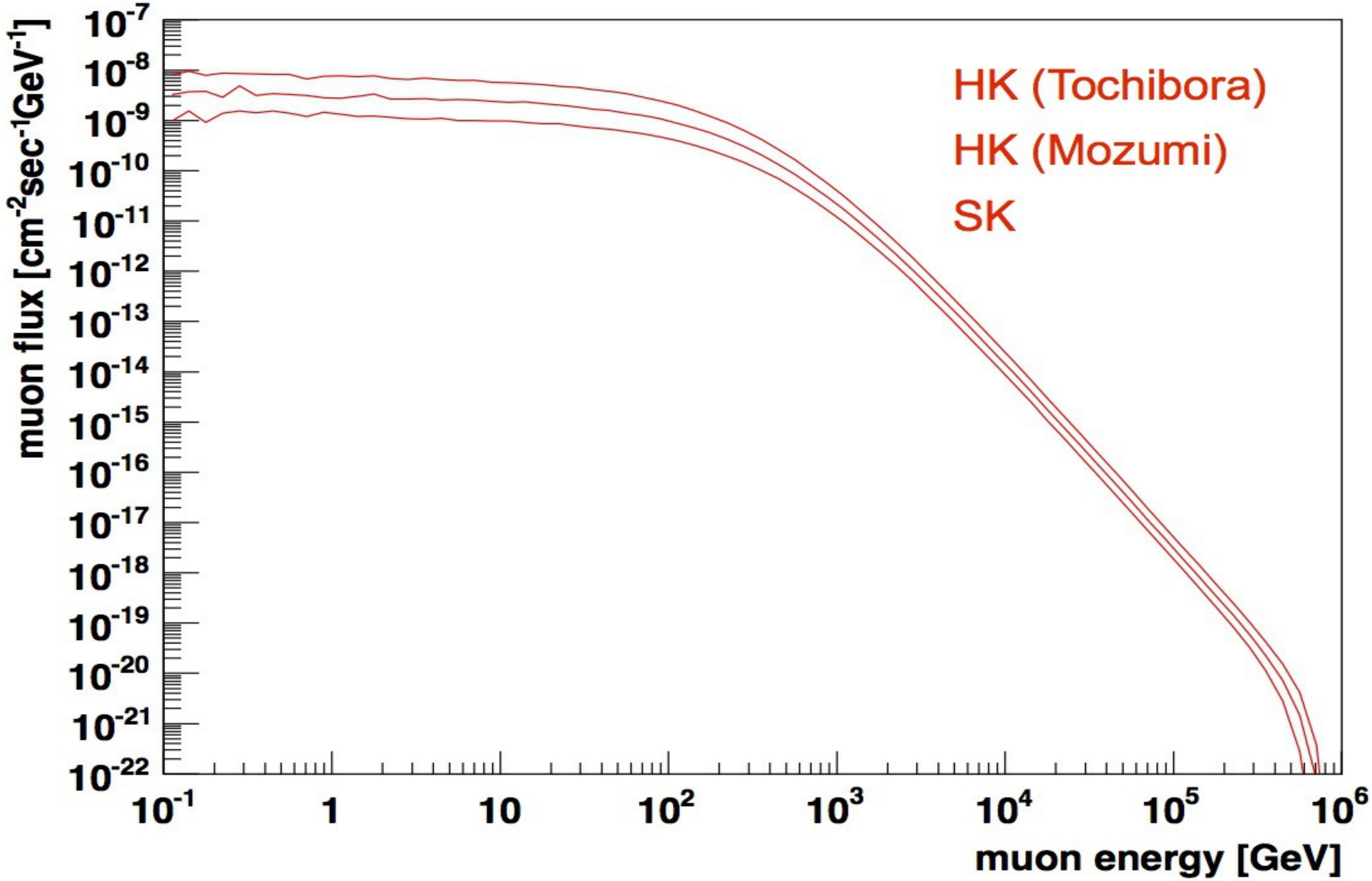
HK muon direction





(cosθ, Φ) SK Data
(cosθ, Φ) SK MC
HK Mozumi MC
HK Tochibora MC
cosθ
ϕ [deg]
E
N
W
S
muon flux [cm^-2 s^-1 sr^-1]
× 10^-8
× 10^-7

HK muon energy : MC



	muon flux	muon average energy
Tochibora (basing point)	7.55×10^{-7} cm^{-2}s^{-1}	203 GeV
Mozumi (center)	3.39×10^{-7} cm^{-2}s^{-1}	228 GeV
SK	1.54×10^{-7} cm^{-2}s^{-1}	258 GeV

Summary: Muon Flux at HK

Summary of MC (MUSIC)

	Muon flux	Muon average energy
HK (Mozumi*)	**3.44×10^{-7} cm^{-2}s^{-1}**	**227 GeV**
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	Ratio of Muon Flux (HK/SK)
HK (Mozumi*)	**2.23 ± 0.45**
HK (Mozumi, basing point)	**1.59 ± 0.32**
HK (Tochibora*)	**5.36 ± 1.07 (new)**
HK (Tochibora, basing point)	**4.90 ± 0.98**

Spallation production rate ×2 and ×4 are expected for Mozumi and Tochibora, respectively.

* : average of all HK

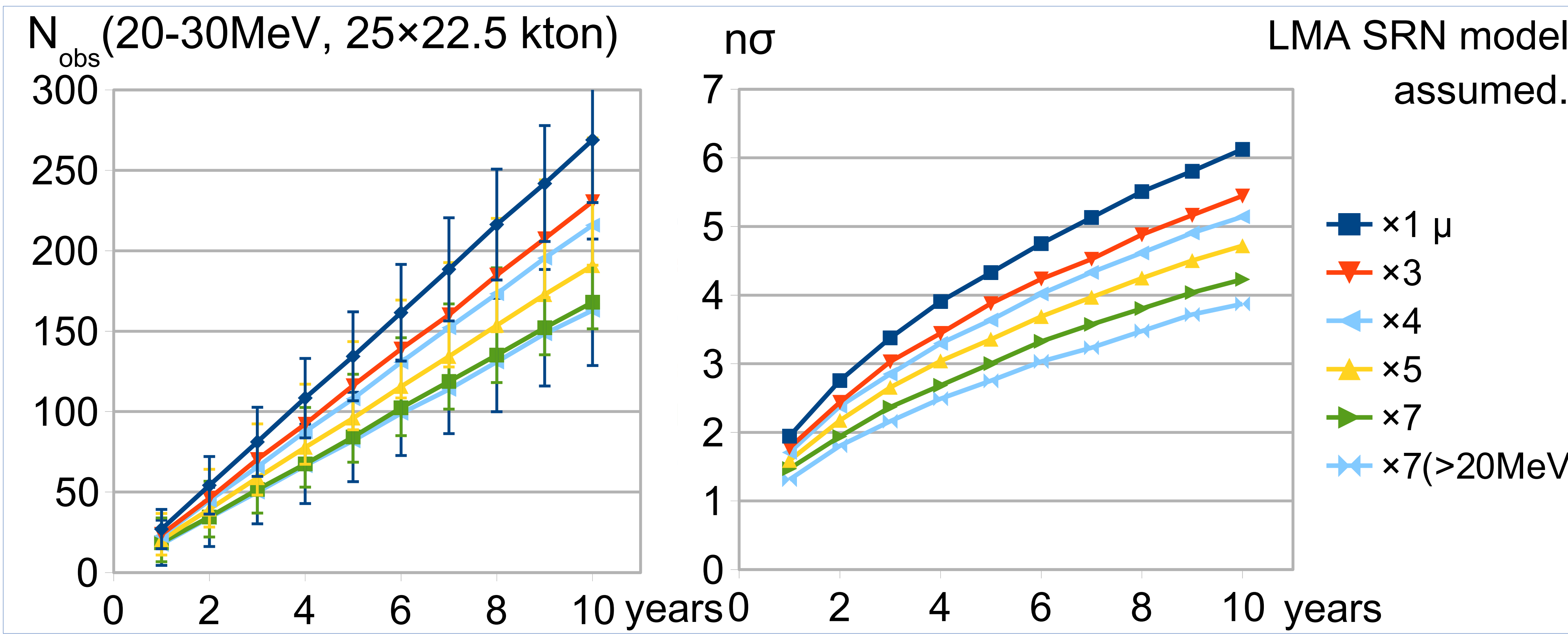
SRN Search with HK

Status so far :

# of SRN events and non-0 significance with HK (pure water) were studied.

- ~270 ev. (20-30 MeV) and ~6σ for ×1μ 10y run.
- ~180 ev. and ~4.5σ for ×5μ case.

T. Yano,, 3rd open meeting for HK.



SRN Model Recognition with HK + Gd

Adding 0.2% Gadolinium sulfate in HK, it will reduce the backgrounds significantly by e^++n double tagging.

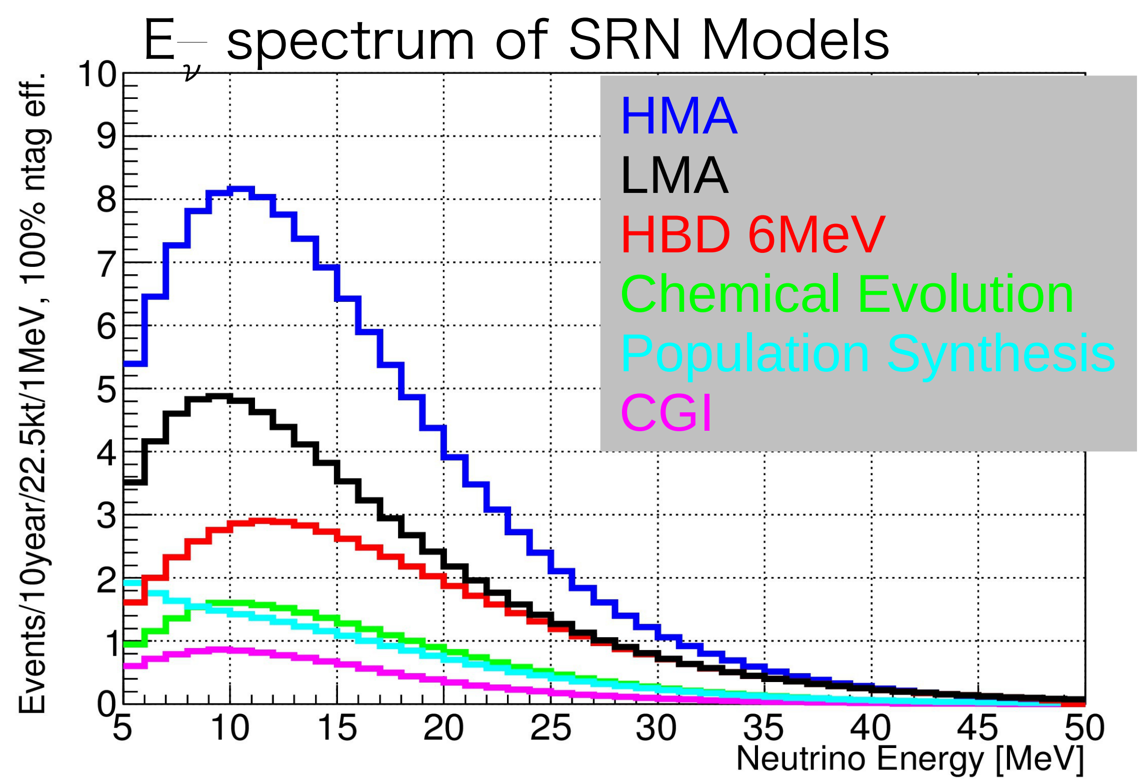
The original idea is for Super Kamiokande, GADZOOKS!.
(Beacom and Vagins (2004)).

This time, SRN model recognition with reduced BG and lower energy threshold is studied.

Characteristics of HK+Gd

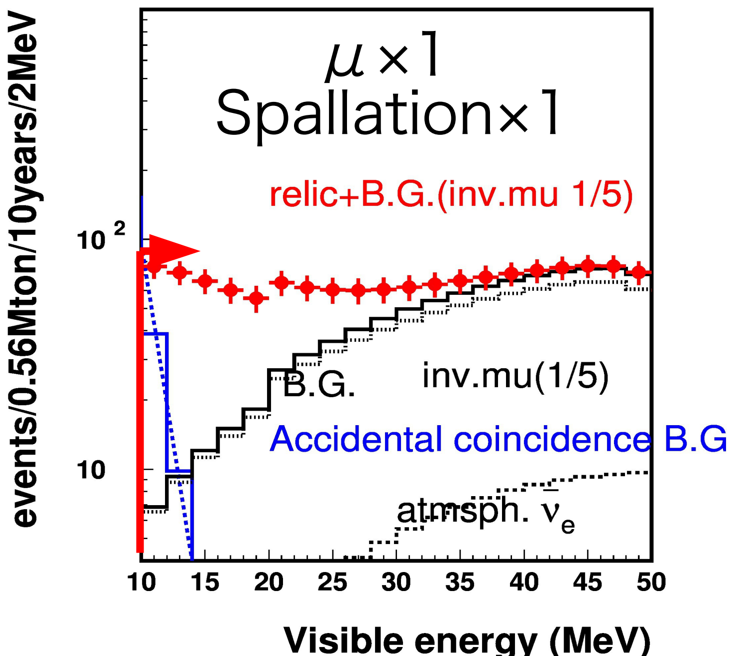
- BG reduction :
  7.0×10^{-5}
- n tag efficiency :
  56% of GADZOOKS!
  = ~37% (=67%×56%)

T. Yano,, 2nd open meeting for HK.

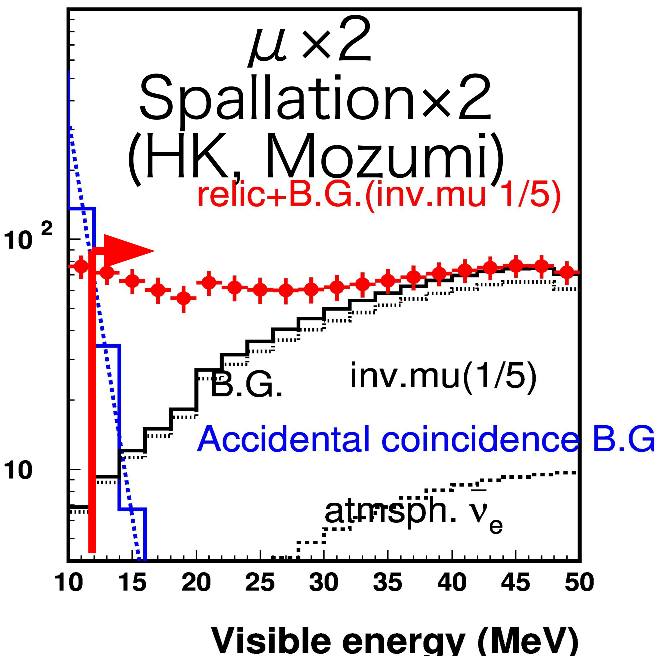


Effect of Spallation Products

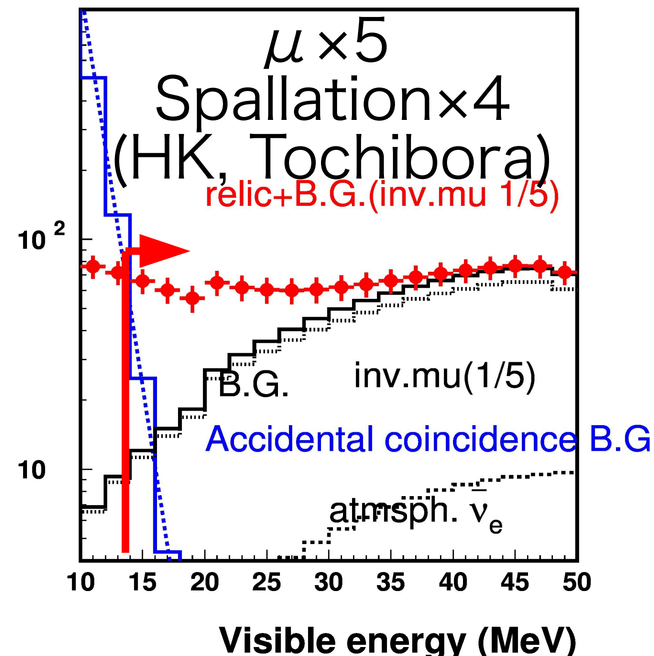
Spallation product is dominant BG for SRN search. Here, energy for SRN search is defined as the region where SRN signal dominates spallation.



E > 10 MeV



E > 12 MeV



E > 14 MeV

SK-IV spallation BG is supposed. Increasing factor for locations are also considered.

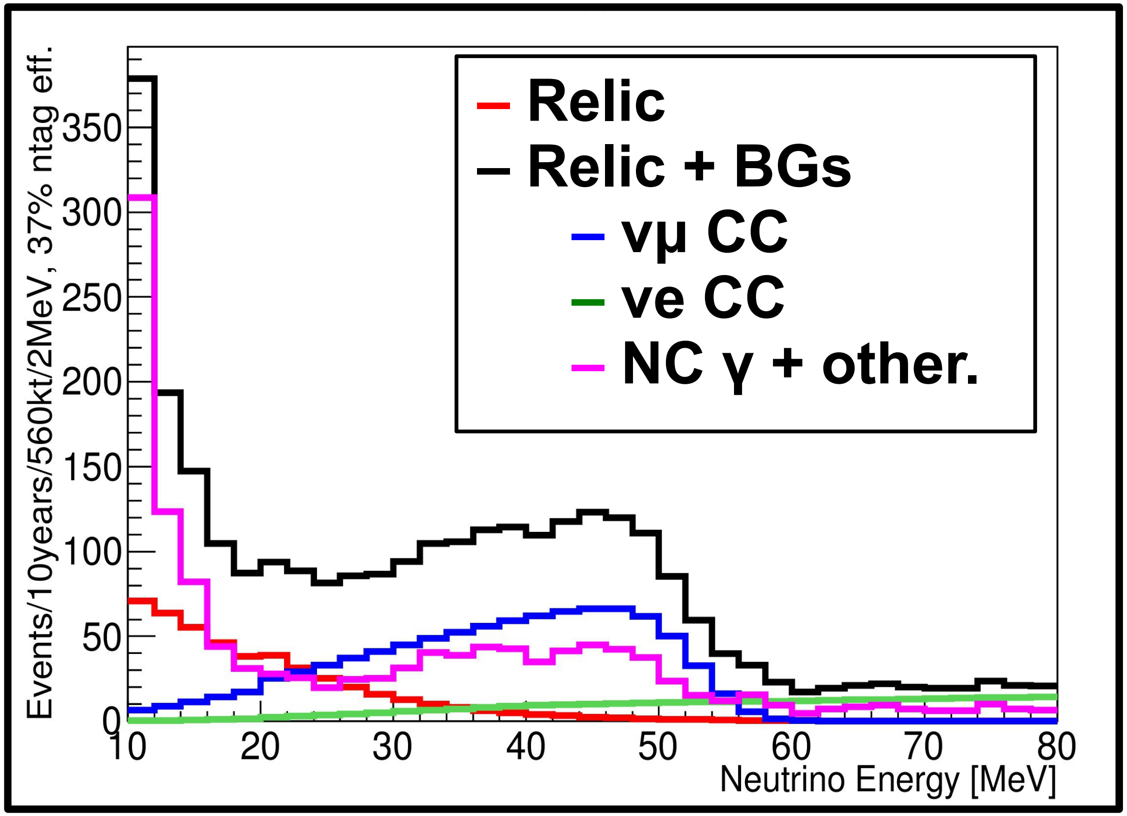
Location effect on spallation BG

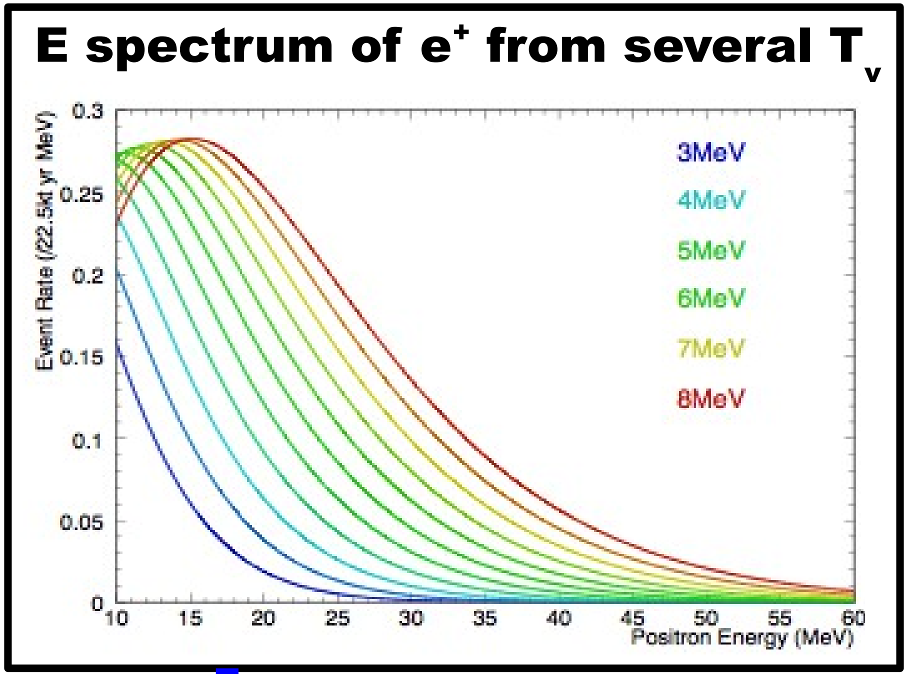
Factor ×1.8 increase ×3.3 increase

w/ Relic spacut	Cosmic μ ×1	×2	×5
Signal Efficiency (E<20)	80%	81%	80%
Remaining spallation	1.2%	2.1%	3.9%

T. Yano, 3rd open meeting for HK.

Spectrum fit for SRN





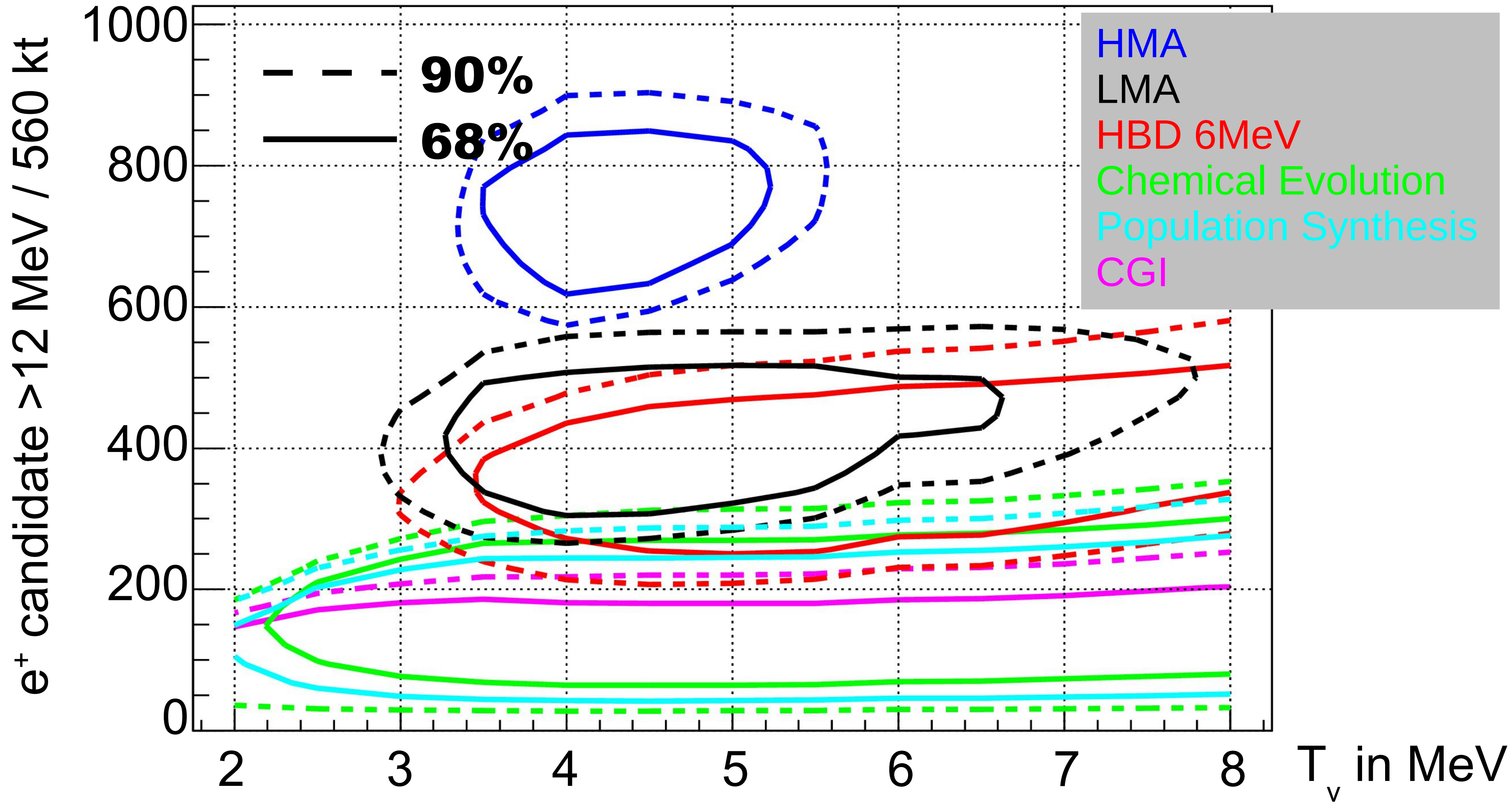
Fit with BGs

1. Event samples are made from BGs and SRN models.
2. The samples are fit with BG and SRN spectra with several T_ν and intensity. Likelihood is calculated for each T_ν and intensity.
3. 2D allowed regions are given on T_ν vs intensity map.

While fitting, it is expected that NC BG intensity is known in the error of ±10%.

SRN Model Recognition

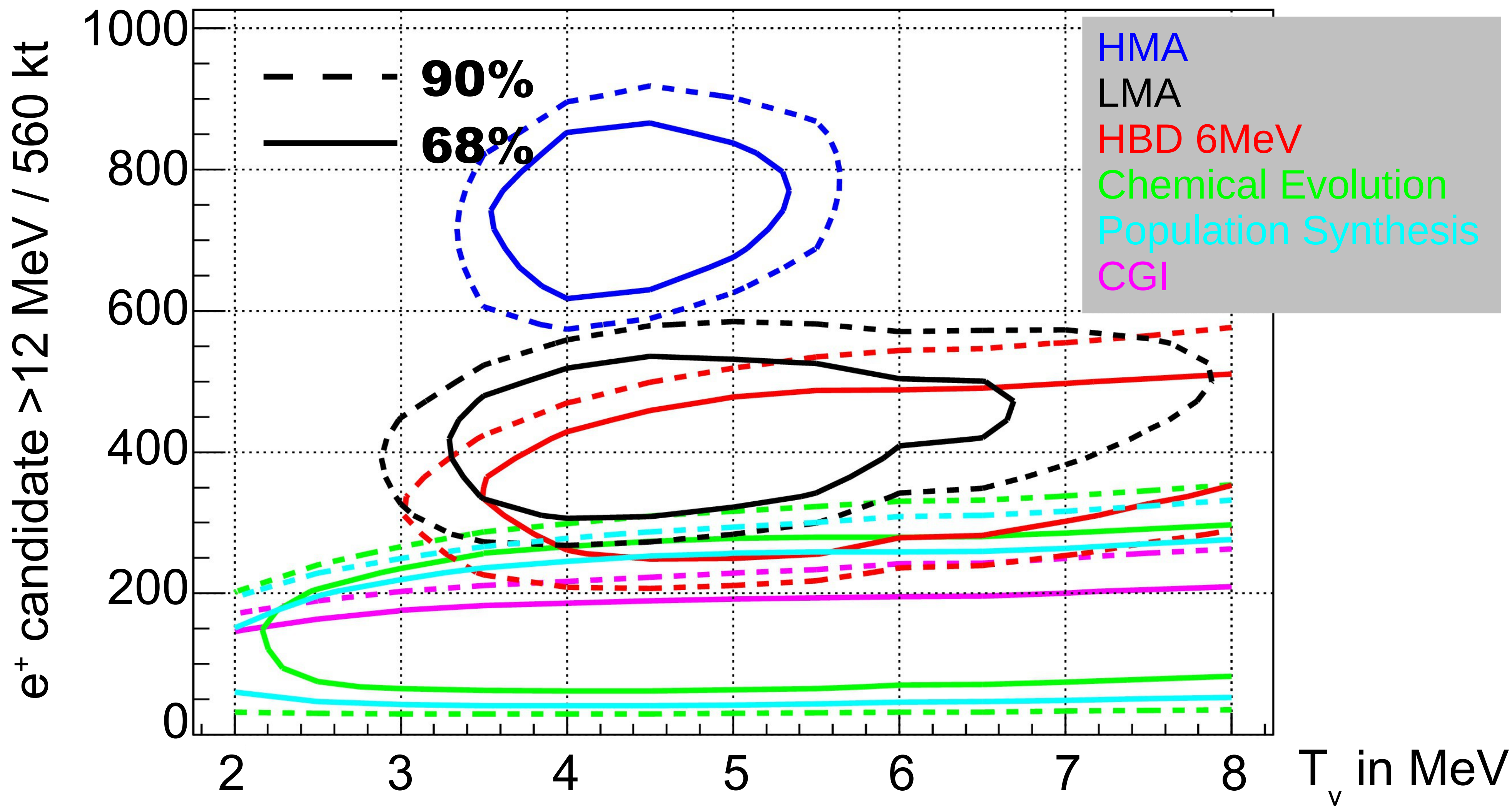
μ ×1, 10years HK



LMA can be distinguished from HMA or other models with > ~90% confidence level, except for HBD 6MeV.
It would be difficult to distinguish LMA and HBD 6MeV.

SRN Model Recognition

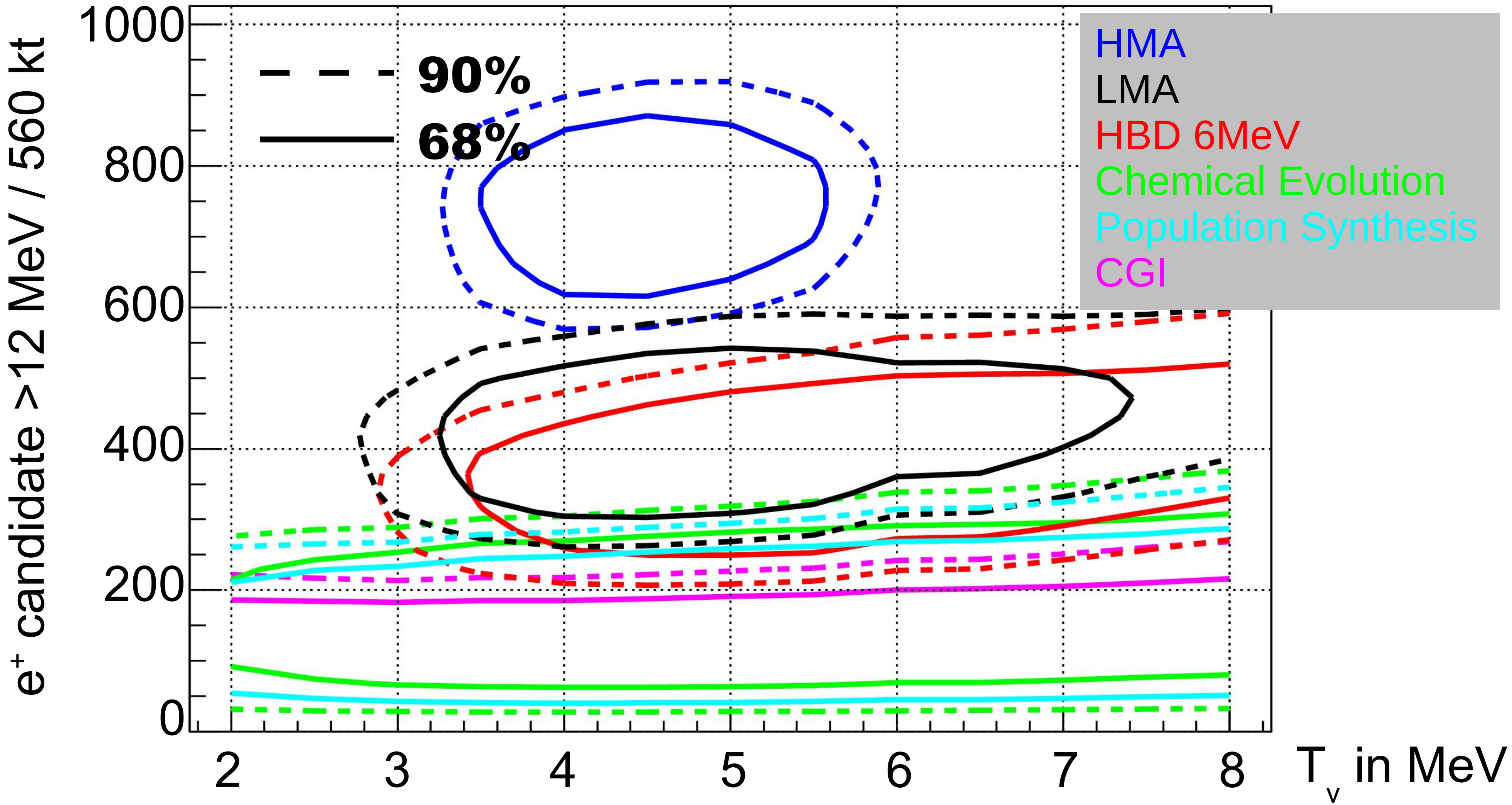
μ ×2, 10years HK



Separation between models is a bit worse than $\mu \times 1$ case.
Outline is mostly same as $\mu \times 1$ case.

SRN Model Recognition

μ ×5, 10years HK



Separation between models becomes worse than $\mu\times 2$ case.
In summary, the difference of $\mu\times 1$, 2 and 5 case does not affect SRN model Recognition dramatically.

Summary

Muon Flux at Mozumi Site, by I. Shimizu (Tohoku Univ.)

- The muon flux at Mozumi site is calculated using MUSIC.

	Ratio of Muon Flux (HK/SK)
HK (Mozumi)	**2.23 ± 0.45**
HK (Tochibora)	**5.36 ± 1.07 (for all HK)**

SRN Search with HK, by T. Yano (Okayama Univ.)

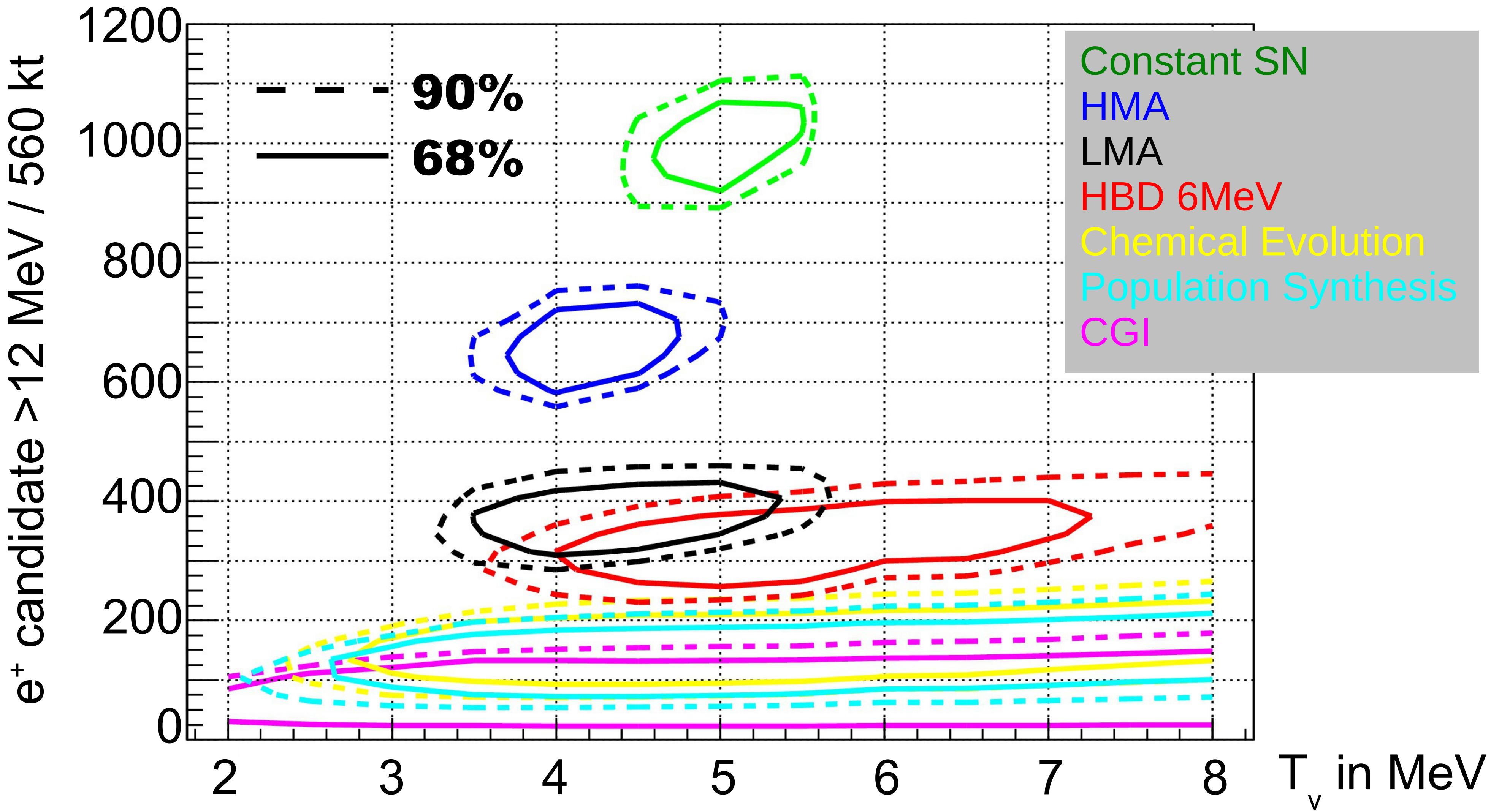
- SRN model recognition is studied for HK + Gd.

  HK+Gd can recognize e.g. LMA model from other models at > ~90% C.L., except for HBD 6MeV.
- The muon flux of ×2 or ×5 does not affect so much on the recognition, but still its' better to have lower mu flux for low energy.

Appendix

SRN Model Identification

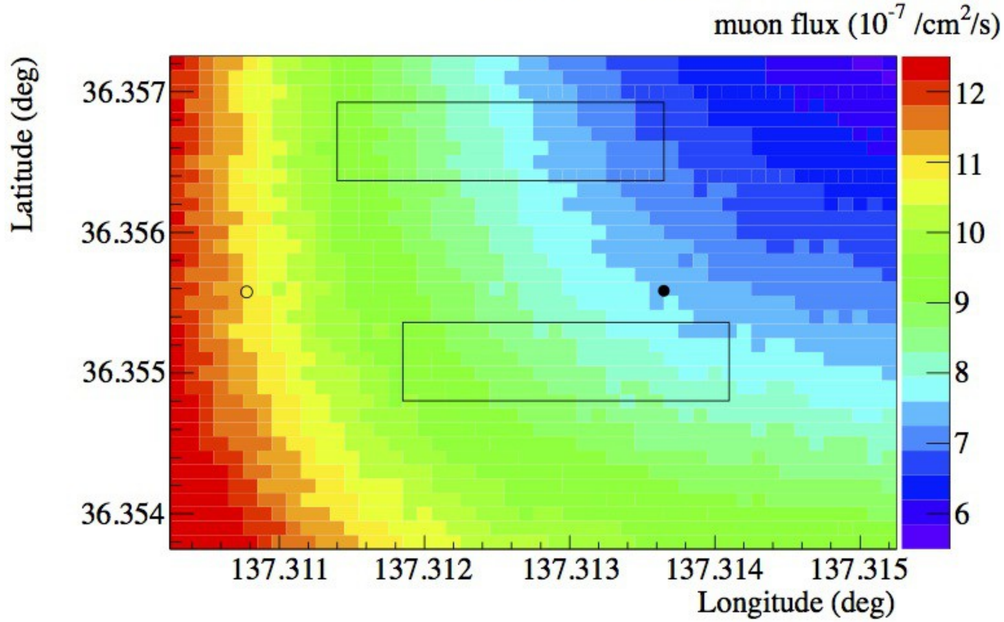
μ ×1 (n tag eff. 67%), 10years HK



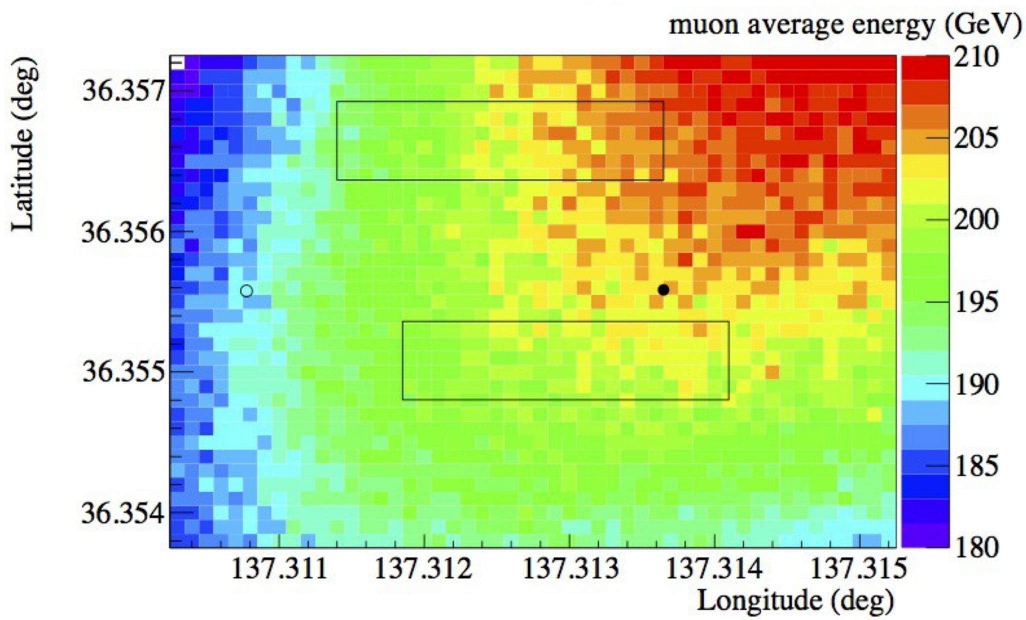
The case of n tag eff. 67 % is also studied.

Muon Simulation at Tochibora

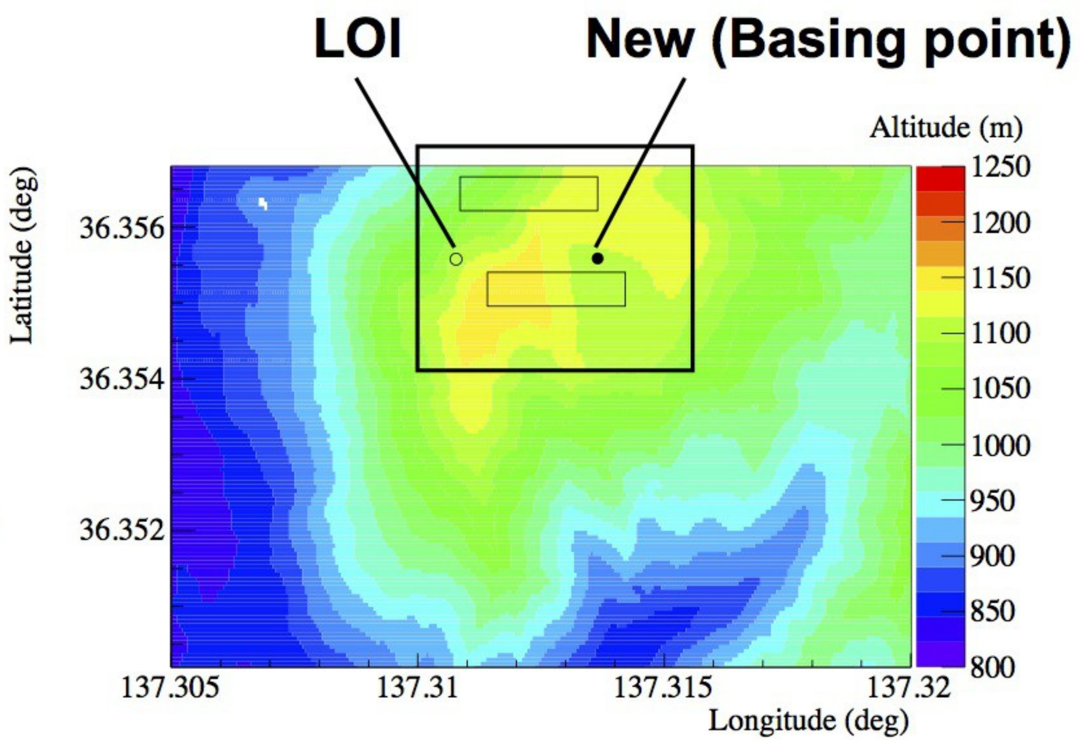
muon flux



muon average energy



HK position



shallower in the west and south

↓

higher flux and lower energy

Muon Flux at HK (Mozumi)

Summary of MC (MUSIC)

	muon flux	muon average energy
HK (boring survey point)	**2.45×10^{-7} cm^{-2}s^{-1}**	**242 GeV**
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	ratio of muon flux (HK / SK)
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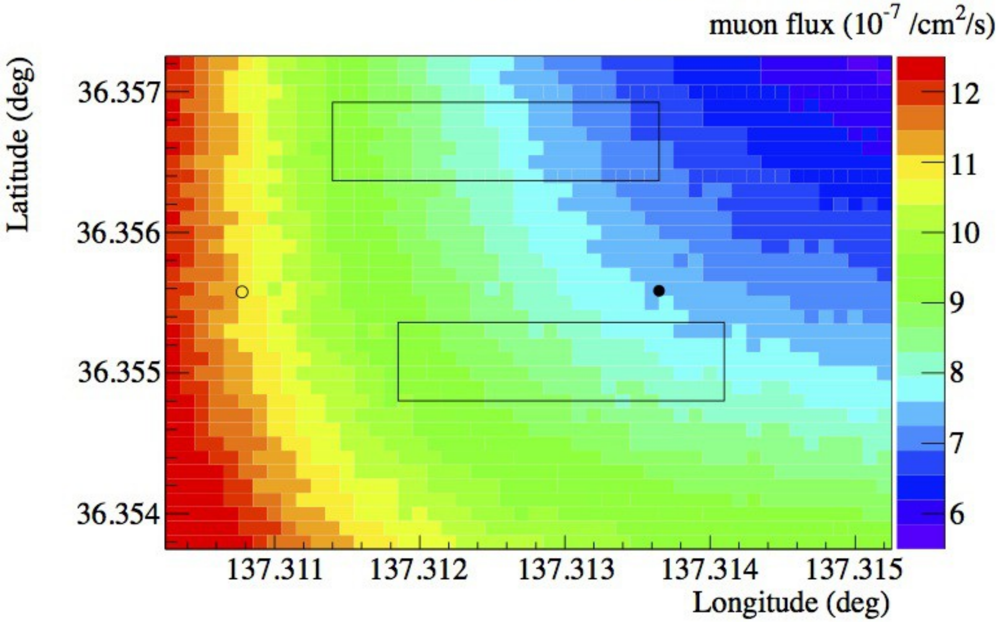
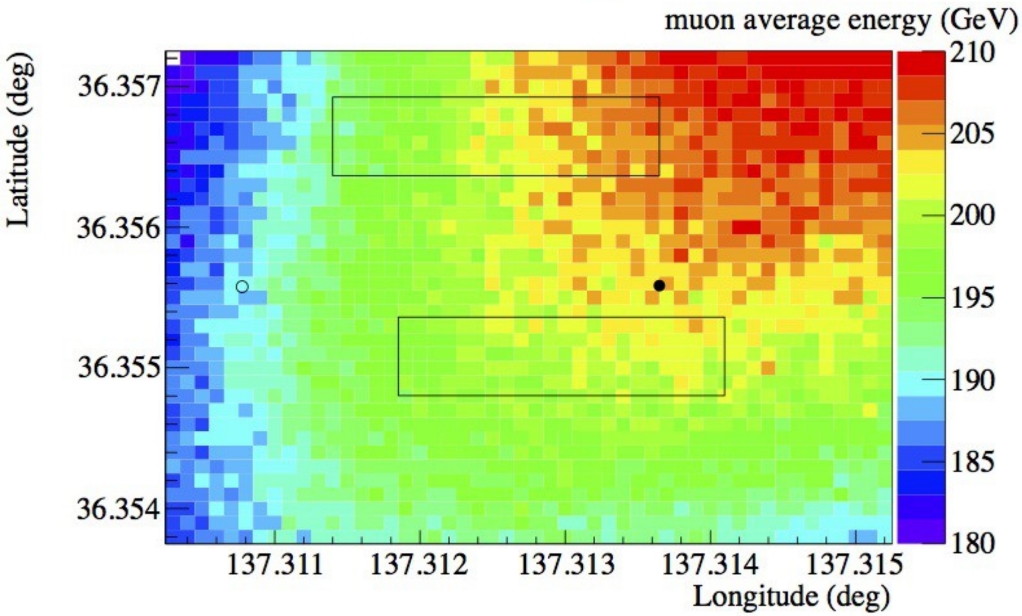
HK	**5.36 ± 1.07**

Muon Simulation at Tochibora

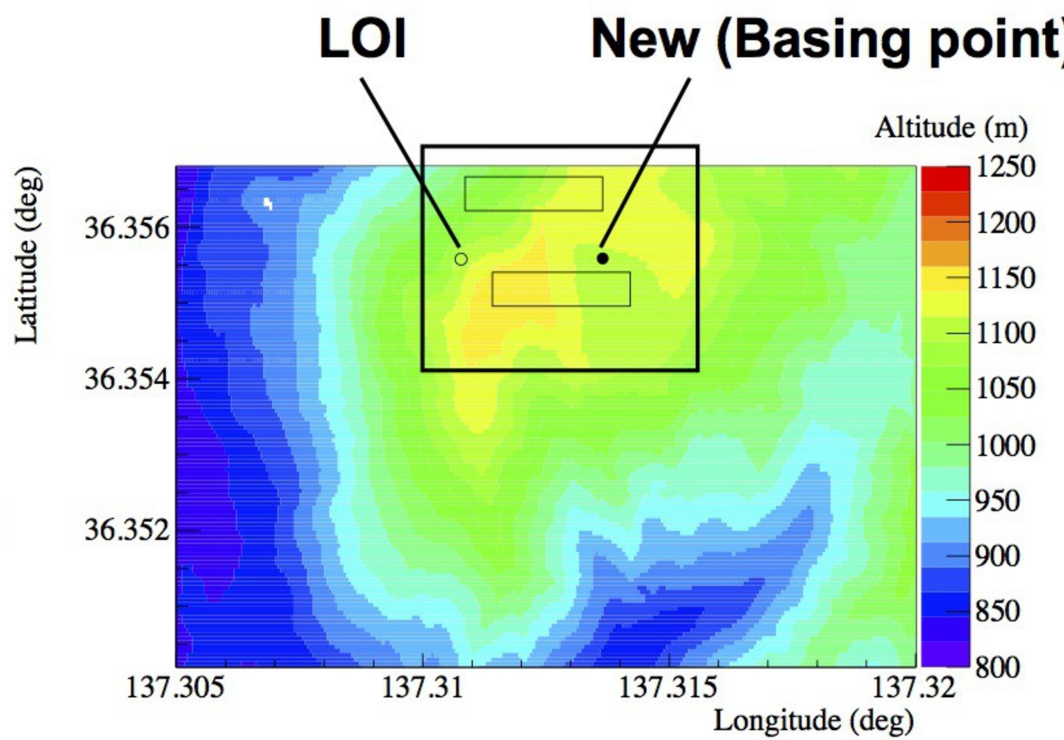
muon flux



muon average energy



HK position



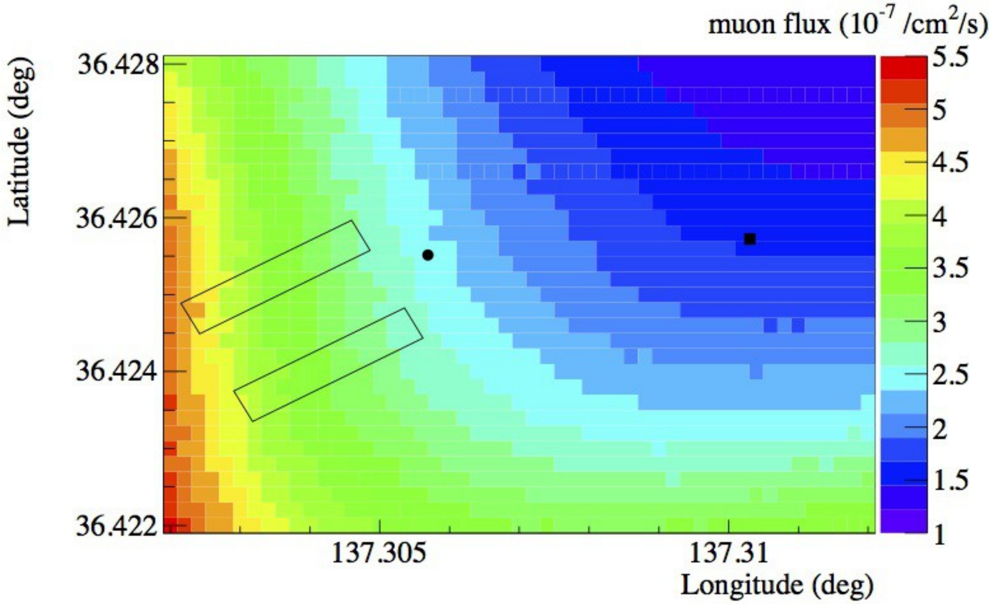
shallower in the west and south

↓

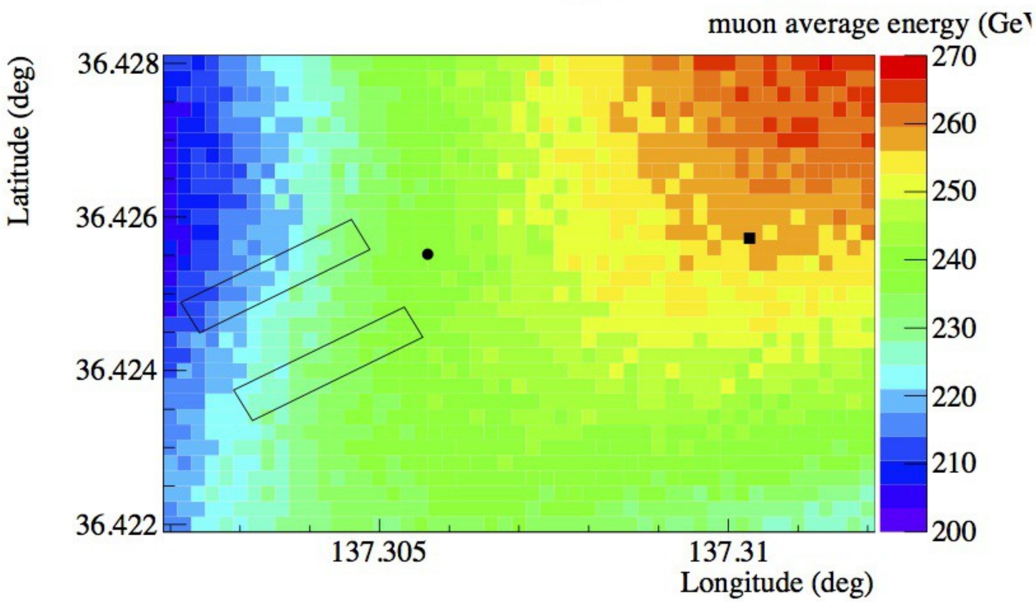
higher flux and lower energy

Muon Simulation at Mozumi

muon flux



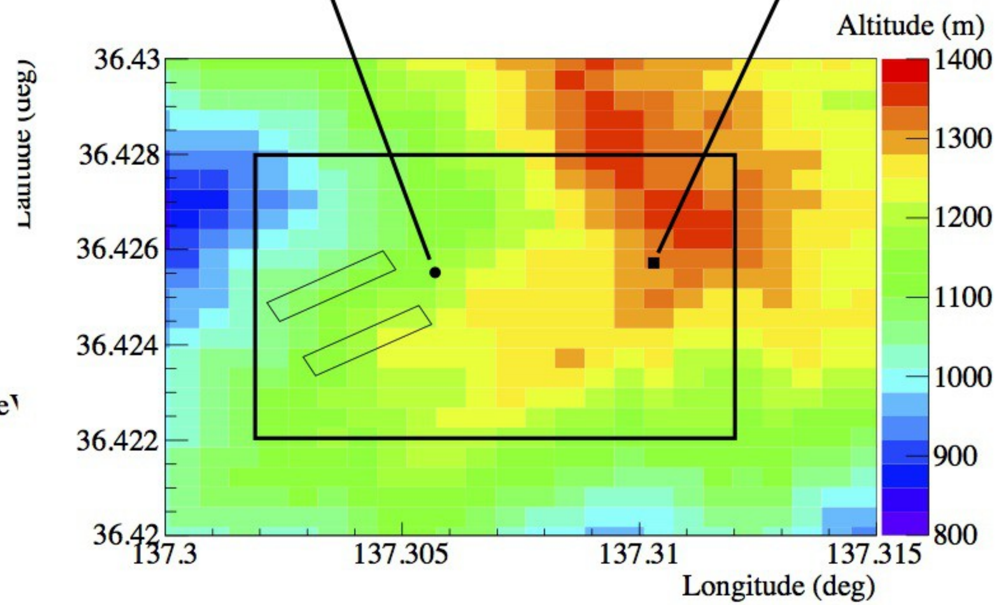
muon average energy



HK position

Boring survey origin

SK



shallower in the west and south

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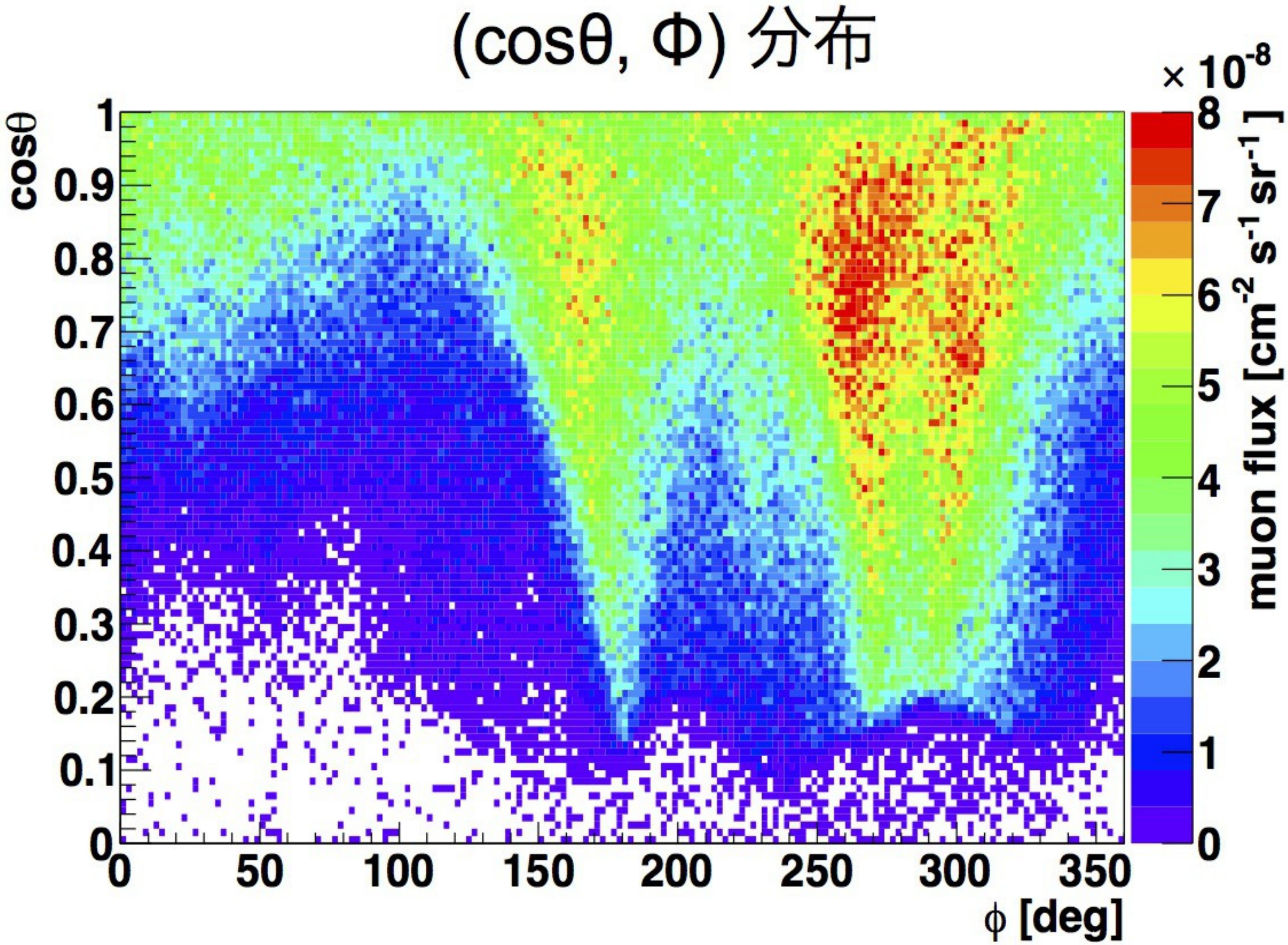
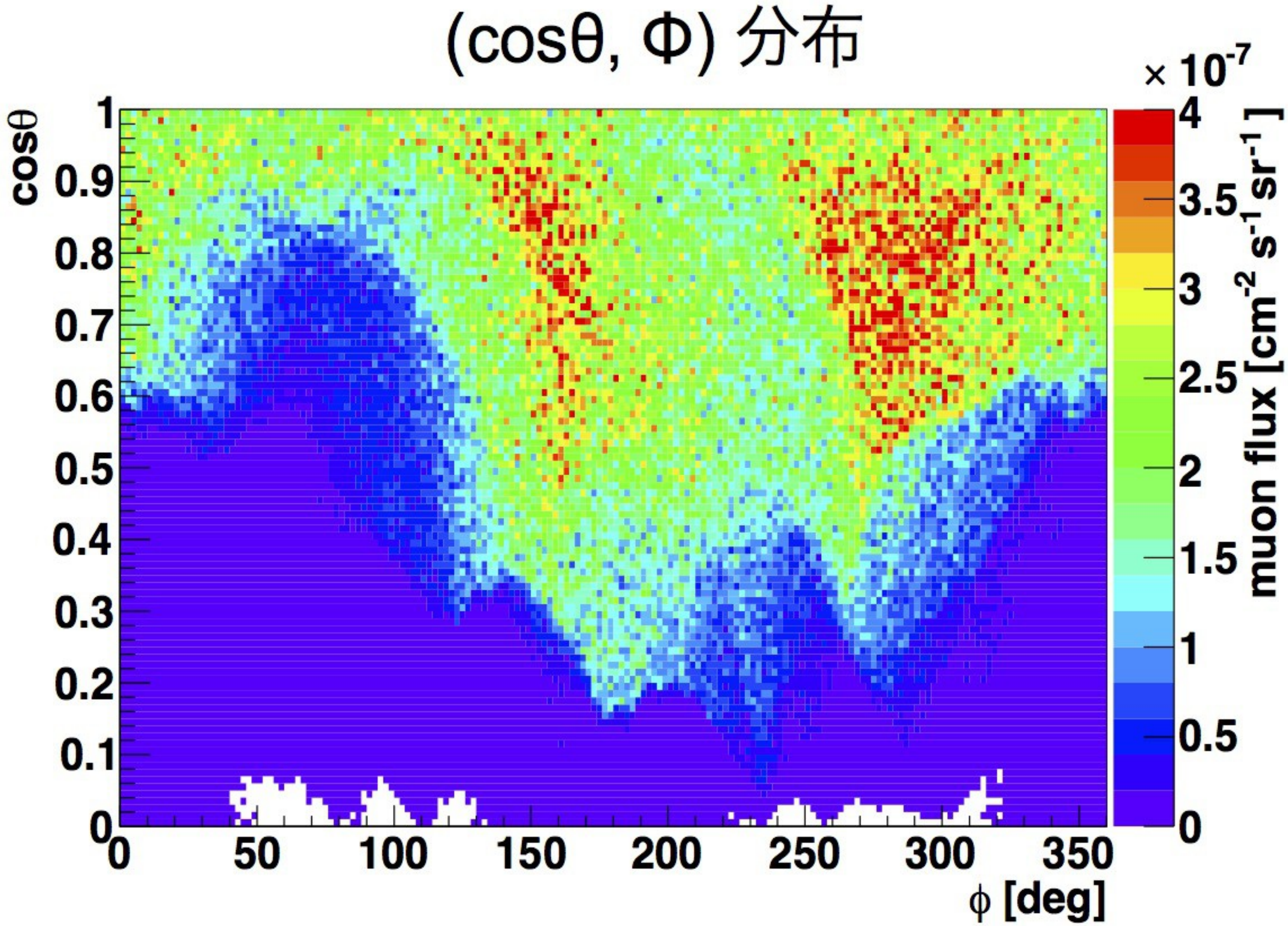
higher flux and lower energy

SK muon direction: Data



HK (Tochibora) muon direction: MC



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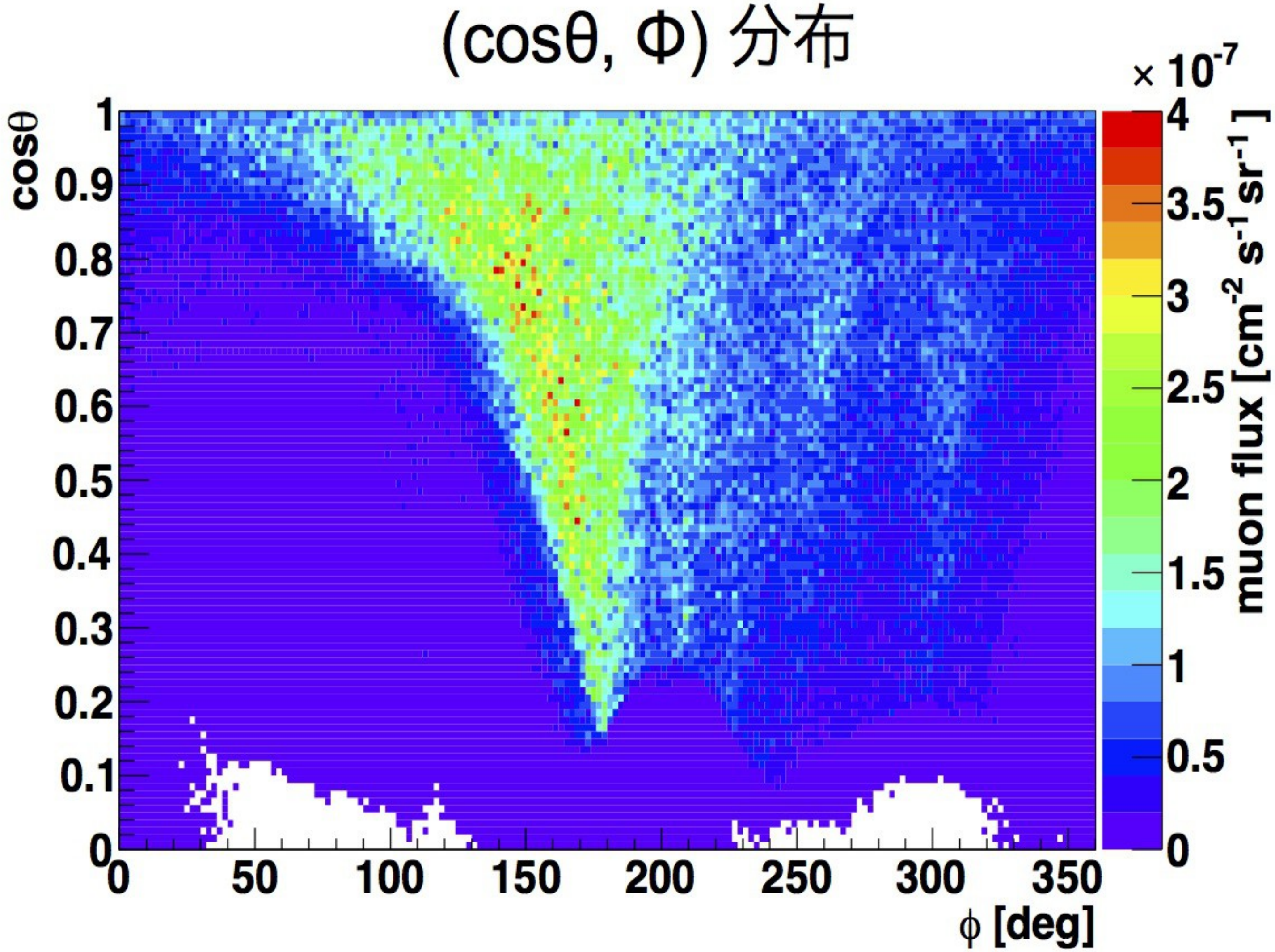
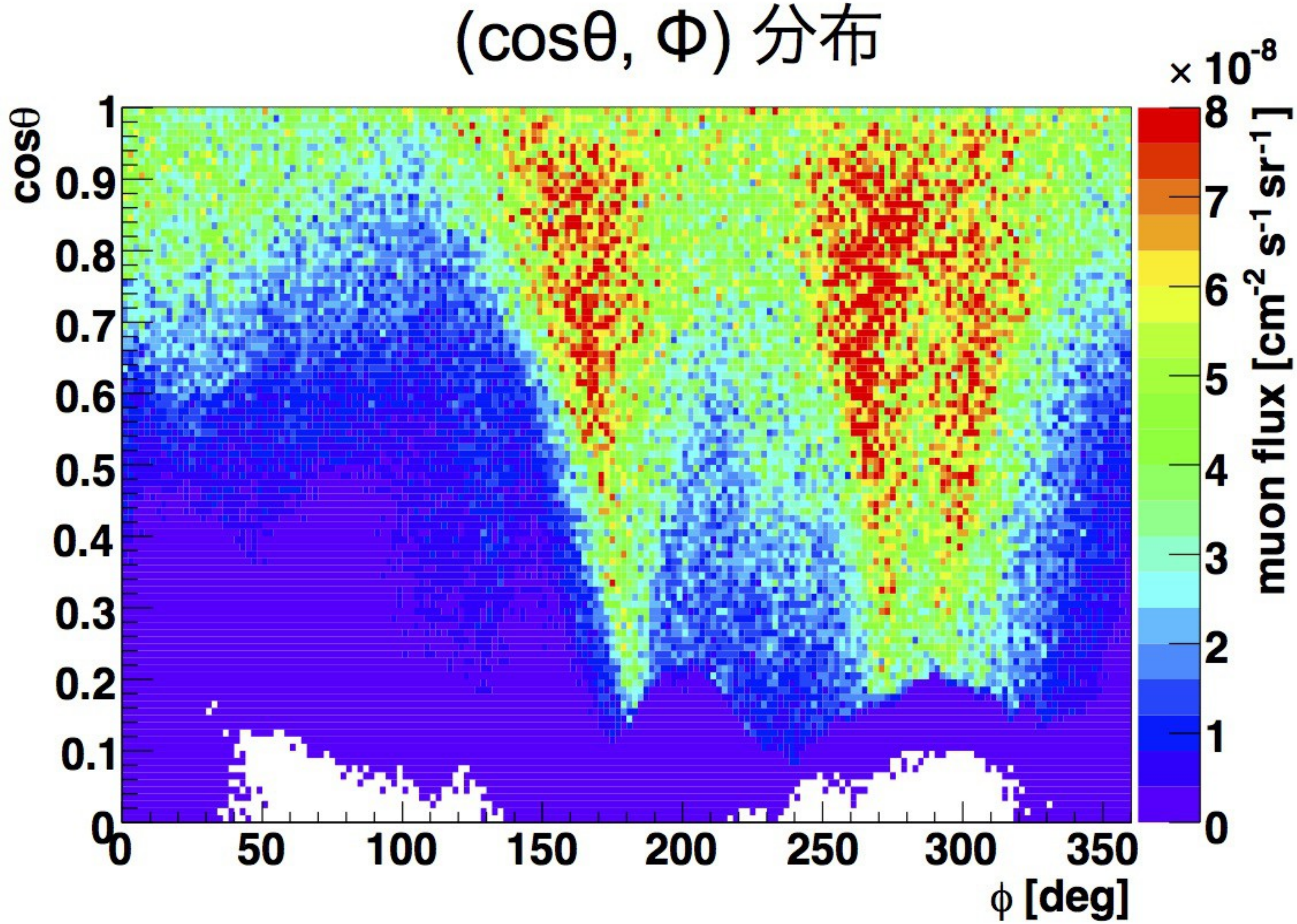
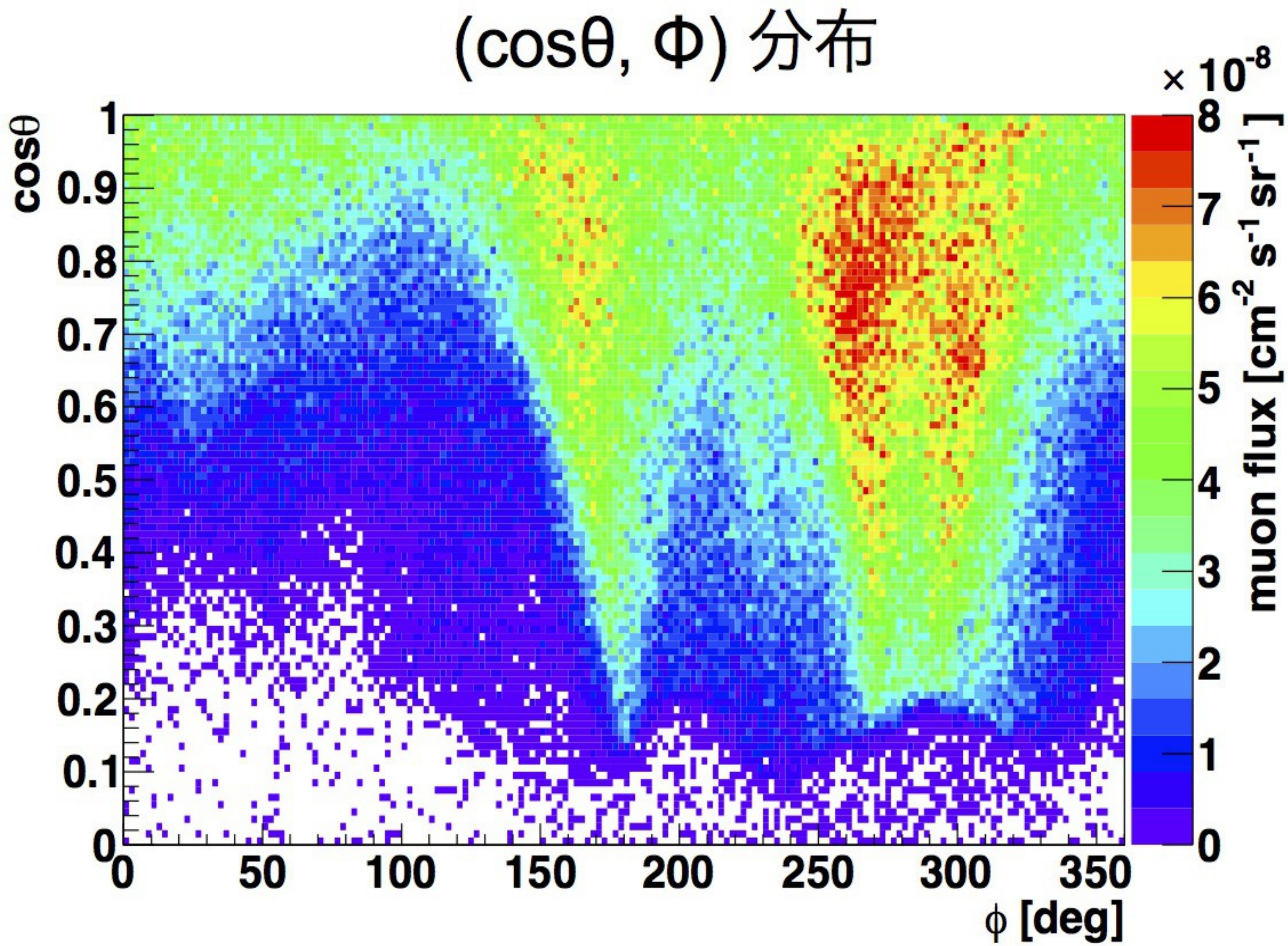


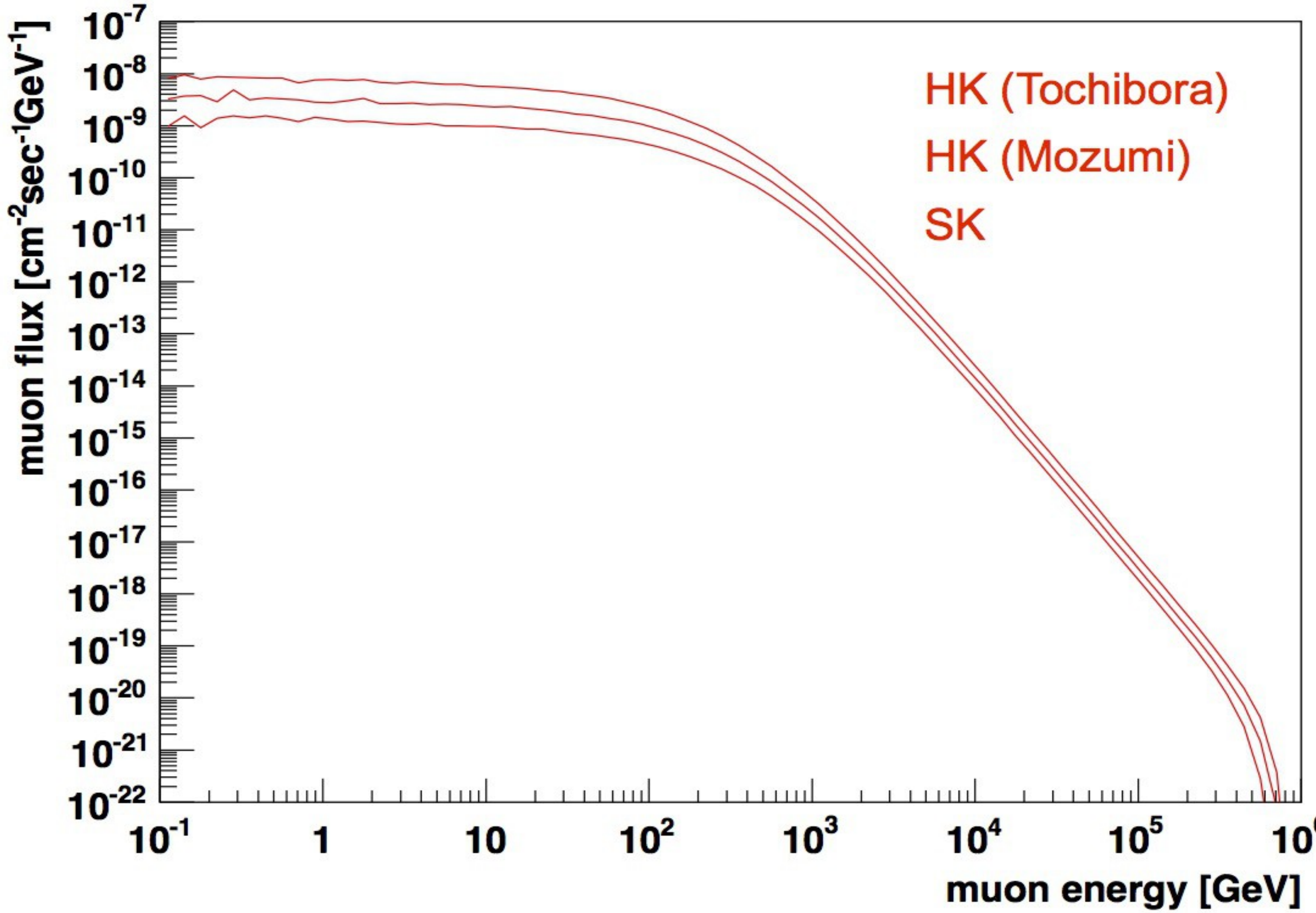
SK muon direction: MC



SK muon direction: Data



HK muon energy: MC



	muon flux	muon average energy
Tochibora (basing point)	7.55×10^{-7} cm^{-2}s^{-1}	203 GeV
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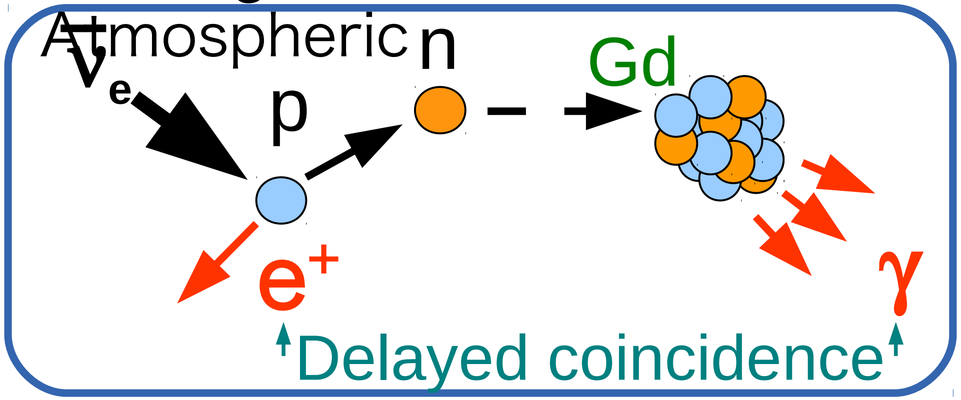
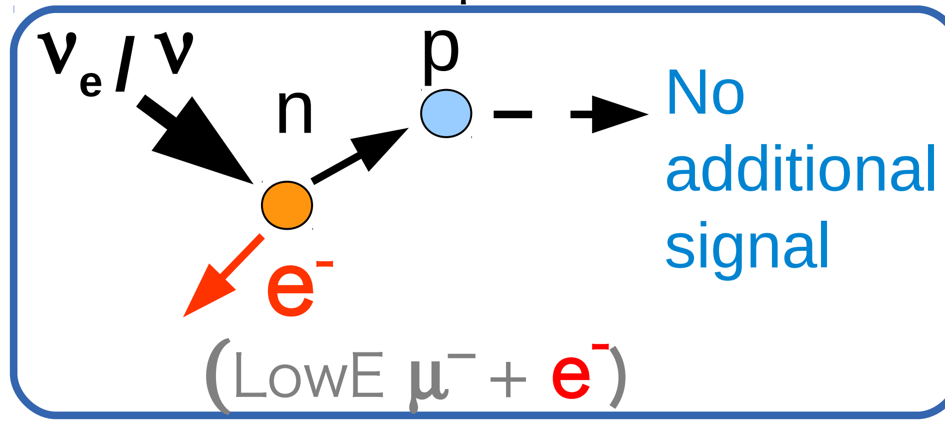
Gadolinium option for HK

SRN signal, Reactor, Atmospheric



Solar, Atmospheric



Adding 0.2% Gadolinium sulfate in HK will reduce the backgrounds significantly by e^+ + n double tagging.

The original idea is for Super Kamiokande (Beacom and Vagins (2004)).

The first study for SK-III was done by Watanabe et. al.(2009).

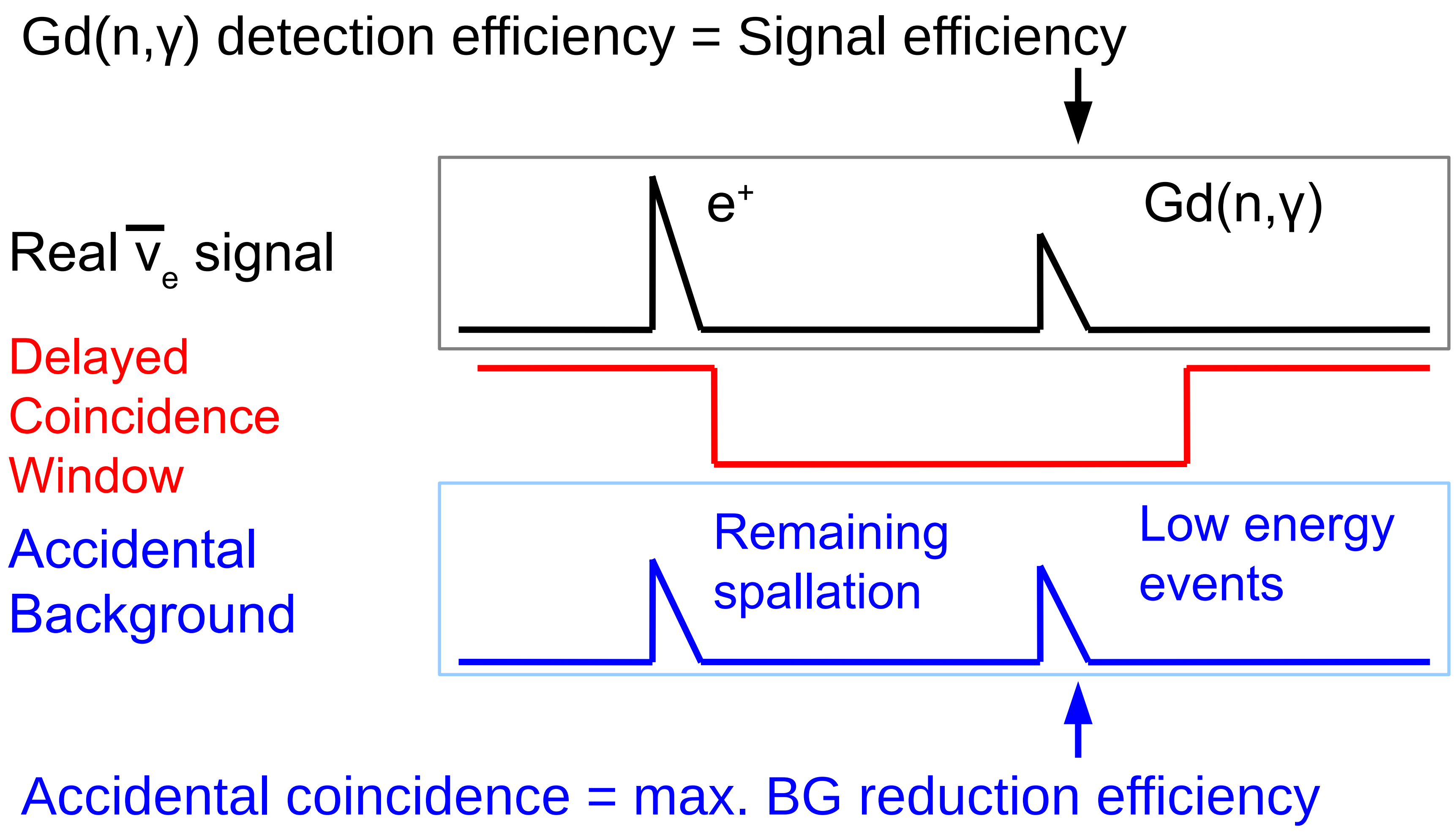
The study for SK-IV was done by Yano and Yamaguchi (2012 Nov. SK Collab.).

No study for Hyper-K, photo coverage 20% and more μ.

Signal efficiency and BG reduction

Double tagging with Gd(n,γ) greatly reduces the background.

Accidental coincidence of background events (spallation etc.) and low-E events (Rn, etc) still exists.



Data samples

Data set : Gd(n,γ) capture events

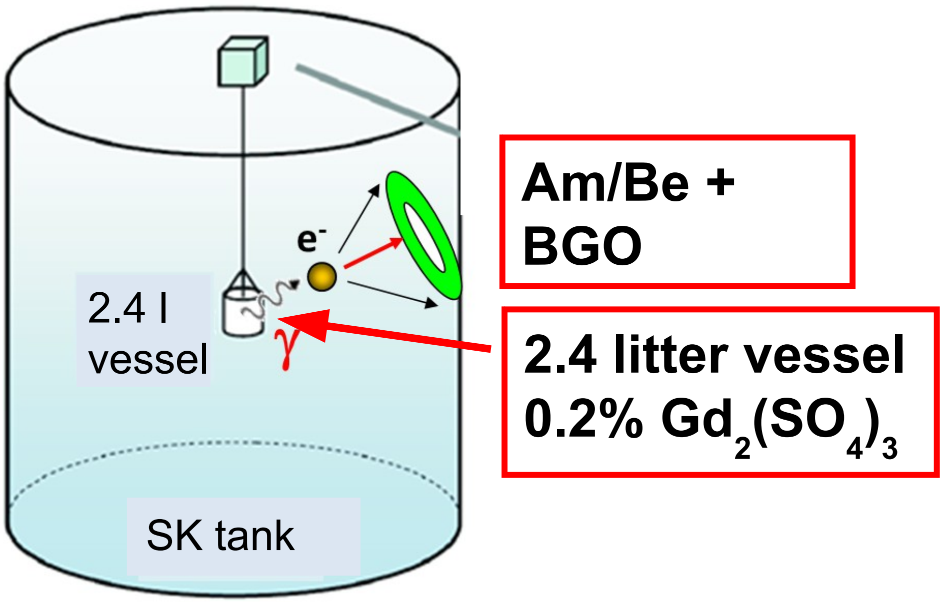
Super-K IV

- taken at 23th Oct. 2010

Source

- Am/Be + BGO + 0.2% $Gd_2(SO_4)_3$
- Neutron is tagged by scintillation of gamma:

  α + Be → C* + n, C* → C + γ



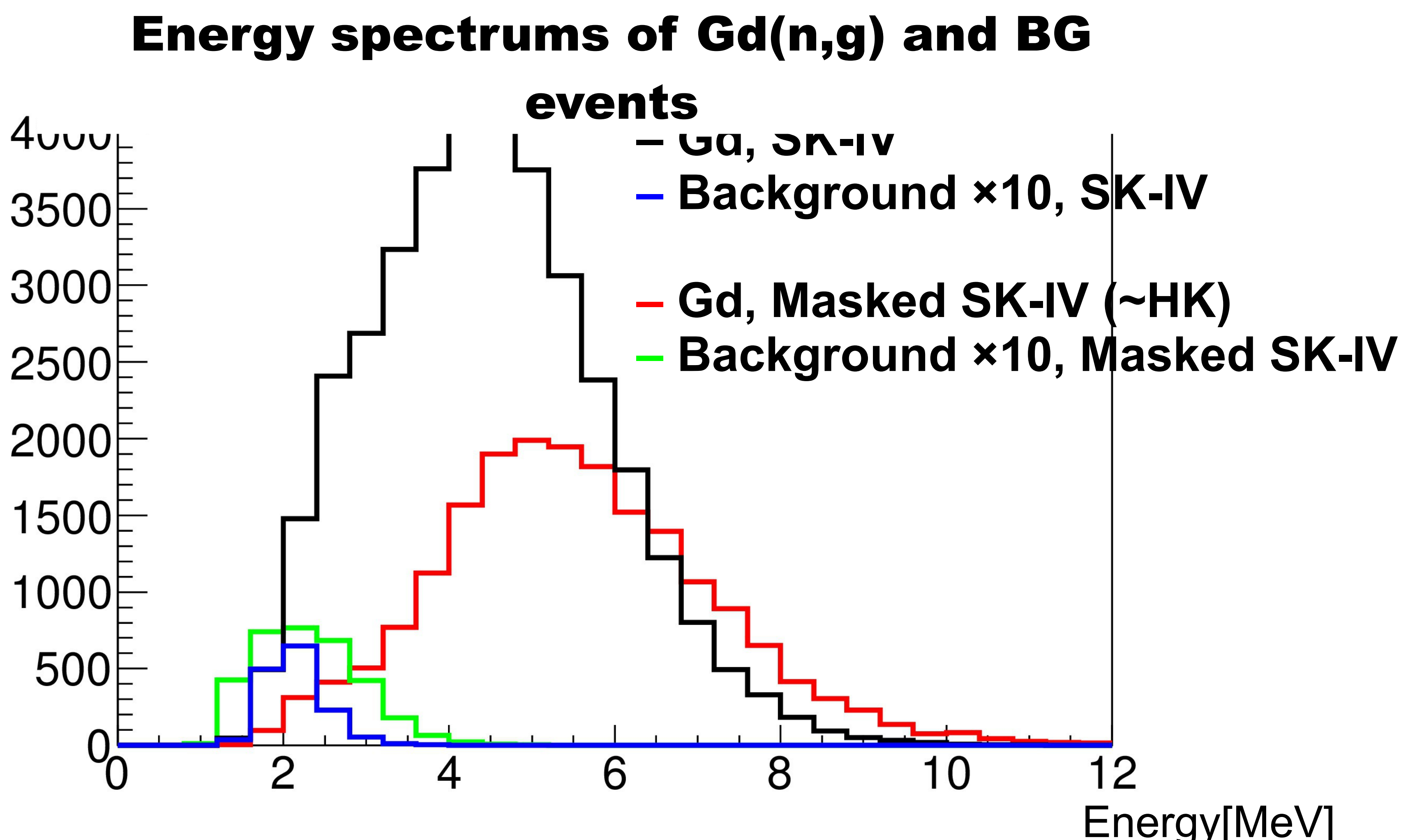
Data set : Background

Super-K IV

- T2K dummy trigger (±500μsec)
- Run 066412 and Run 066415

These data sets are analyzed for 2 cases:
with **normal SK-IV** configuration and with 50% masked SK-IV (photo coverage 19%, equivalent to SK-II (~ HK)).

Gadolinium events and BG

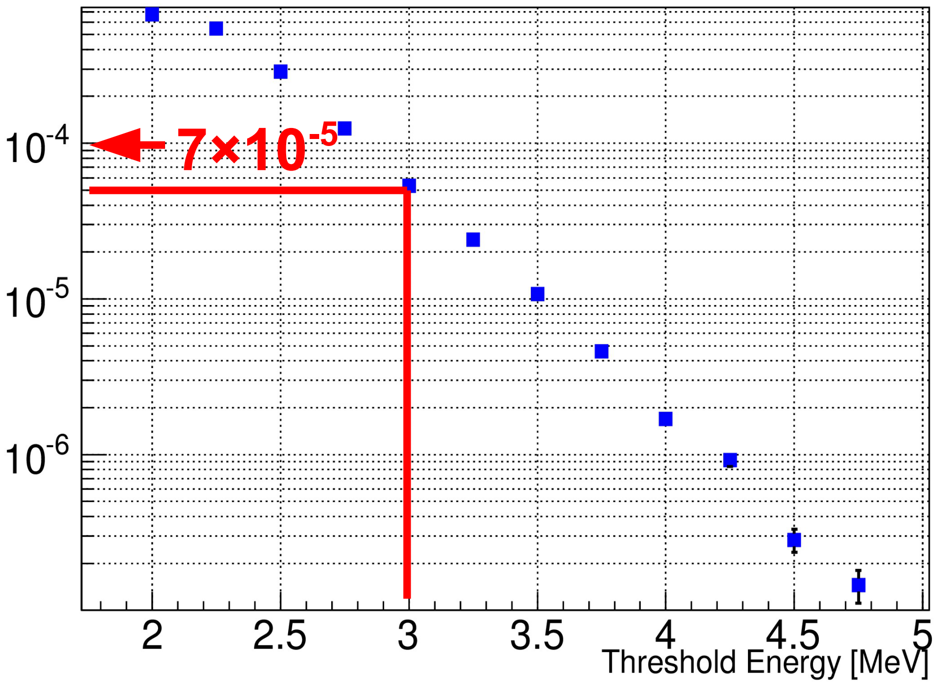


Event selection criteria :

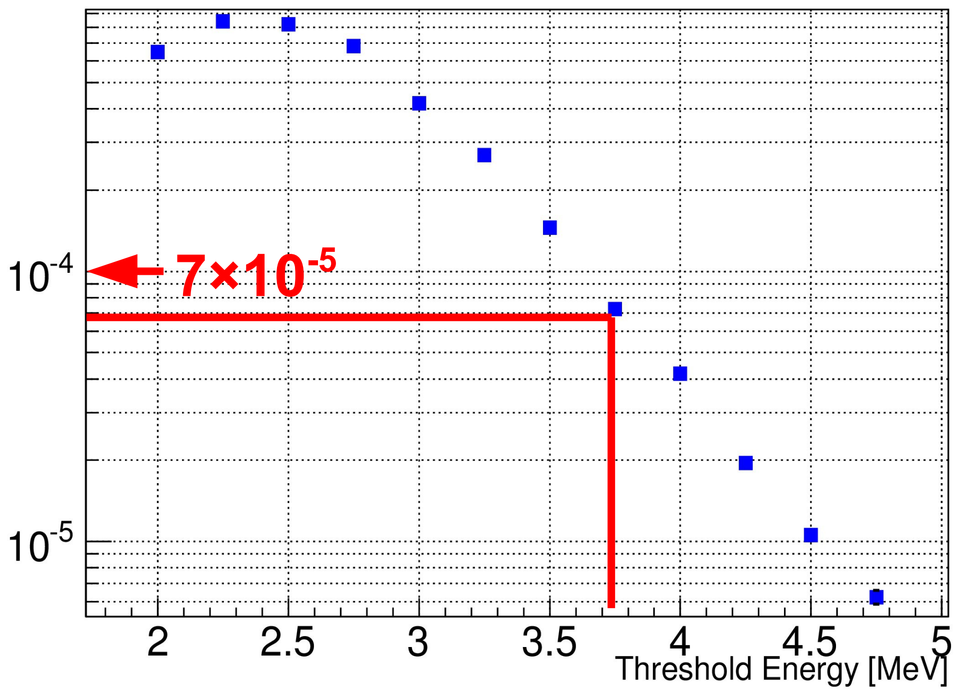
- Distance from source center: R < 2 m
- Event time difference from first trigger: 1.7μs<ΔT<35μs
- Goodness, Dirks, Cherenkov like cut

BG Reduction Efficiency

Reduction Efficiency for <2m, 60μs
Normal SK-IV



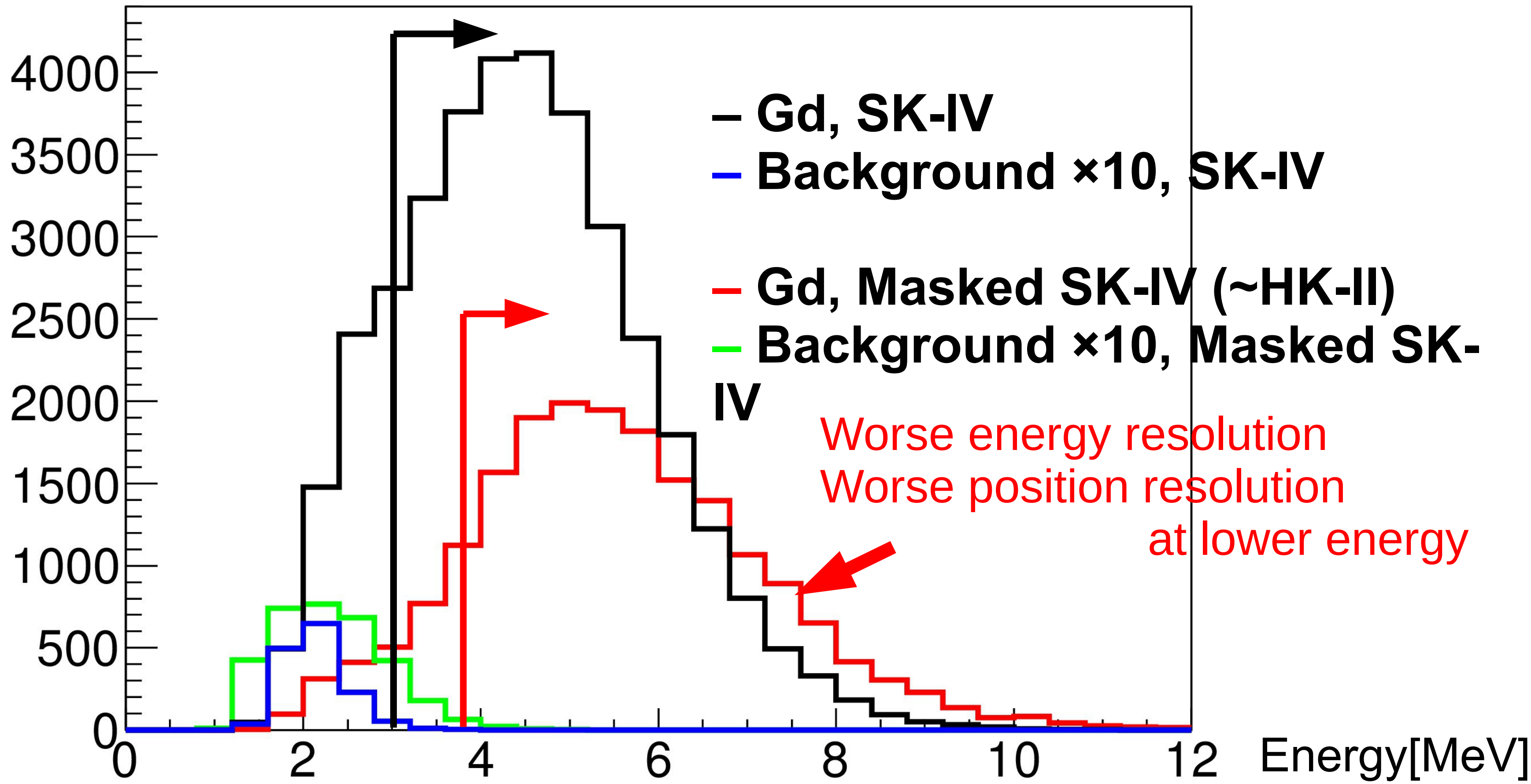
Reduction Efficiency for <2m, 60μs
50% Masked SK-IV



Applying 3.0 MeV threshold, the reduction efficiency 7×10^{-5} can be achieved at SK-IV.

At HK, the same reduction efficiency 7×10^{-5} will be achieved by increasing the threshold to 3.75 MeV.

Gd in HK



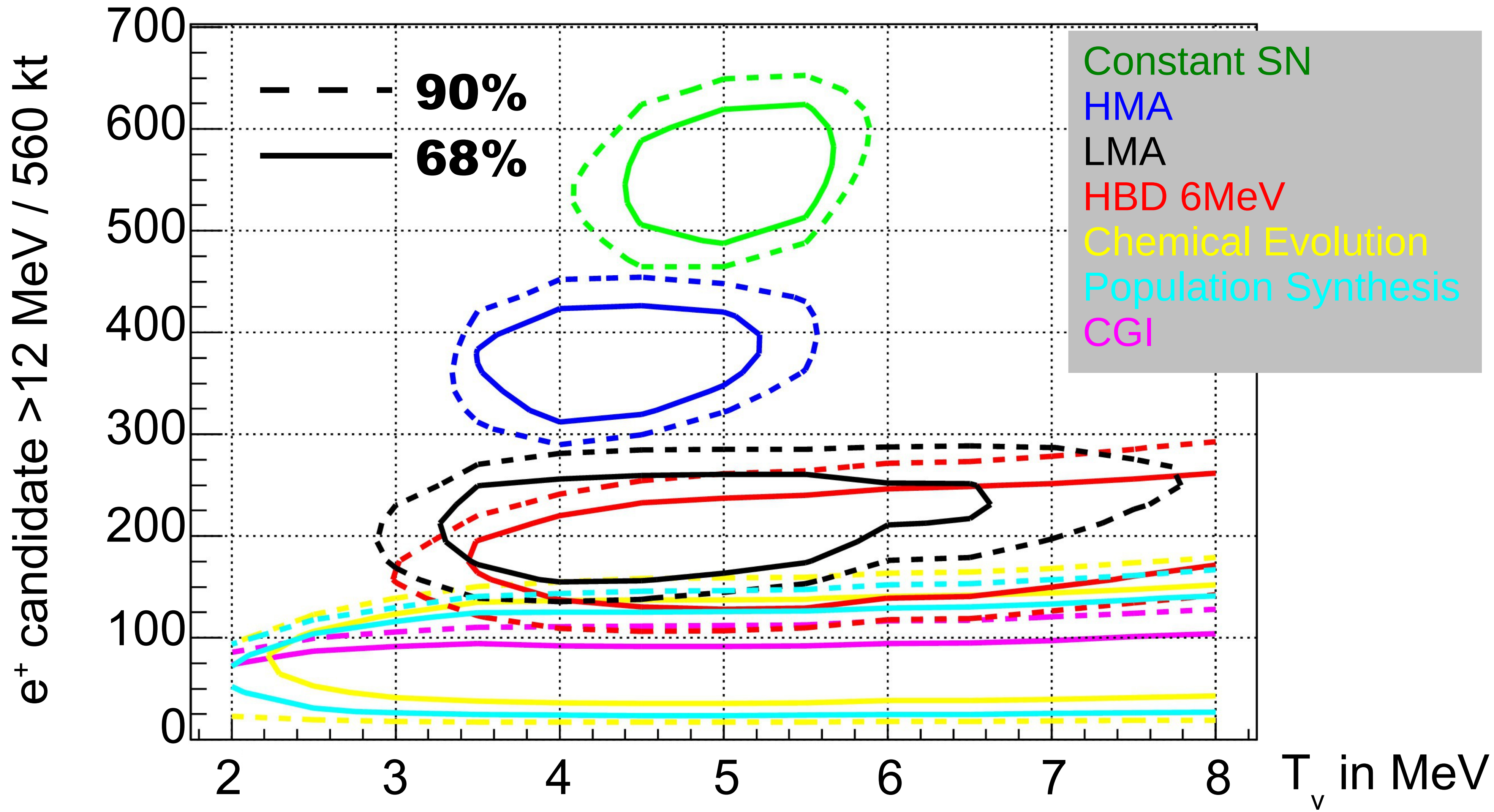
At SK-IV, 92% of Gd(n,γ) events are kept by 3.0 MeV threshold, after R<2.0m selection.

At masked SK-IV (HK), the Gd(n,γ) events become 52% by 3.75 MeV threshold, after R<2.0m selection.

Conclusion: BG reduction efficiency is same as SK-IV, but the signal efficiency become 92% → 52%.

SRN Model Recognition

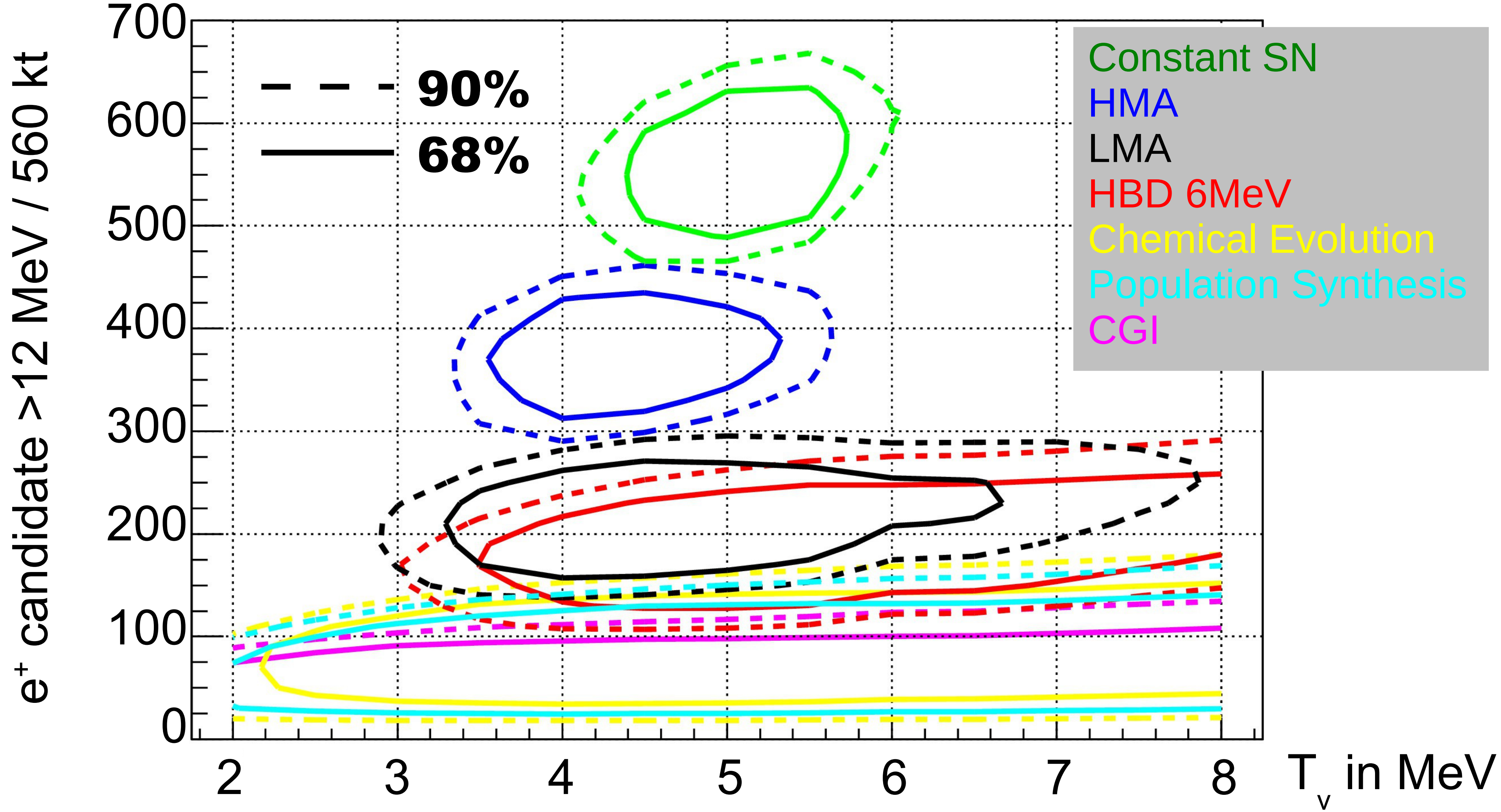
$\mu \times 1$, 10years HK



LMA can be distinguished from HMA, Constant SN or other models with > 90% confidence level, except for HBD 6MeV.
It would be difficult to distinguish LMA and HBD 6MeV.

SRN Model Recognition

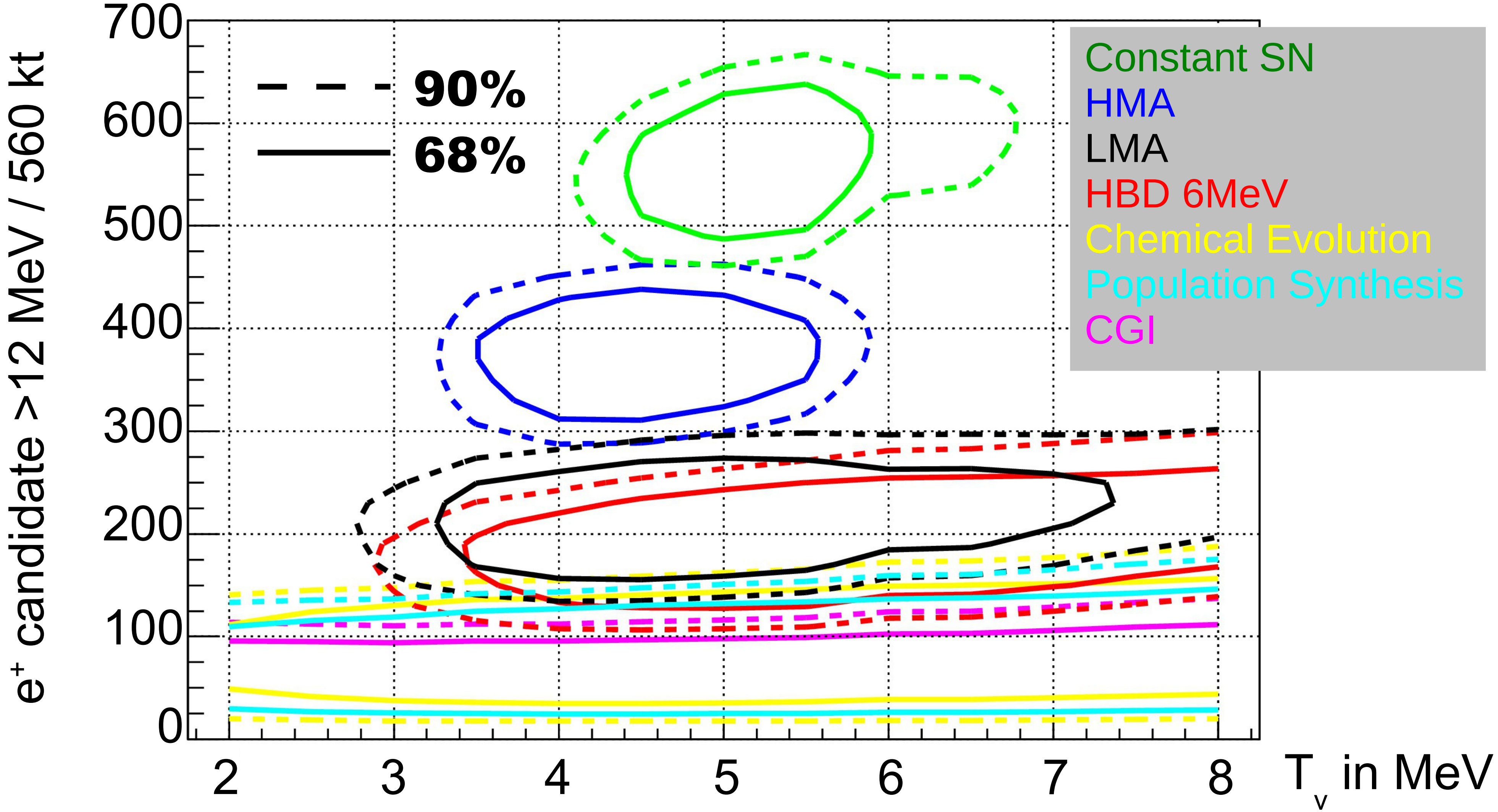
μ ×2, 10years HK



Separation between models is a bit worse than $\mu\times 1$ case.
Outline is mostly same as $\mu\times 1$ case.

SRN Model Recognition

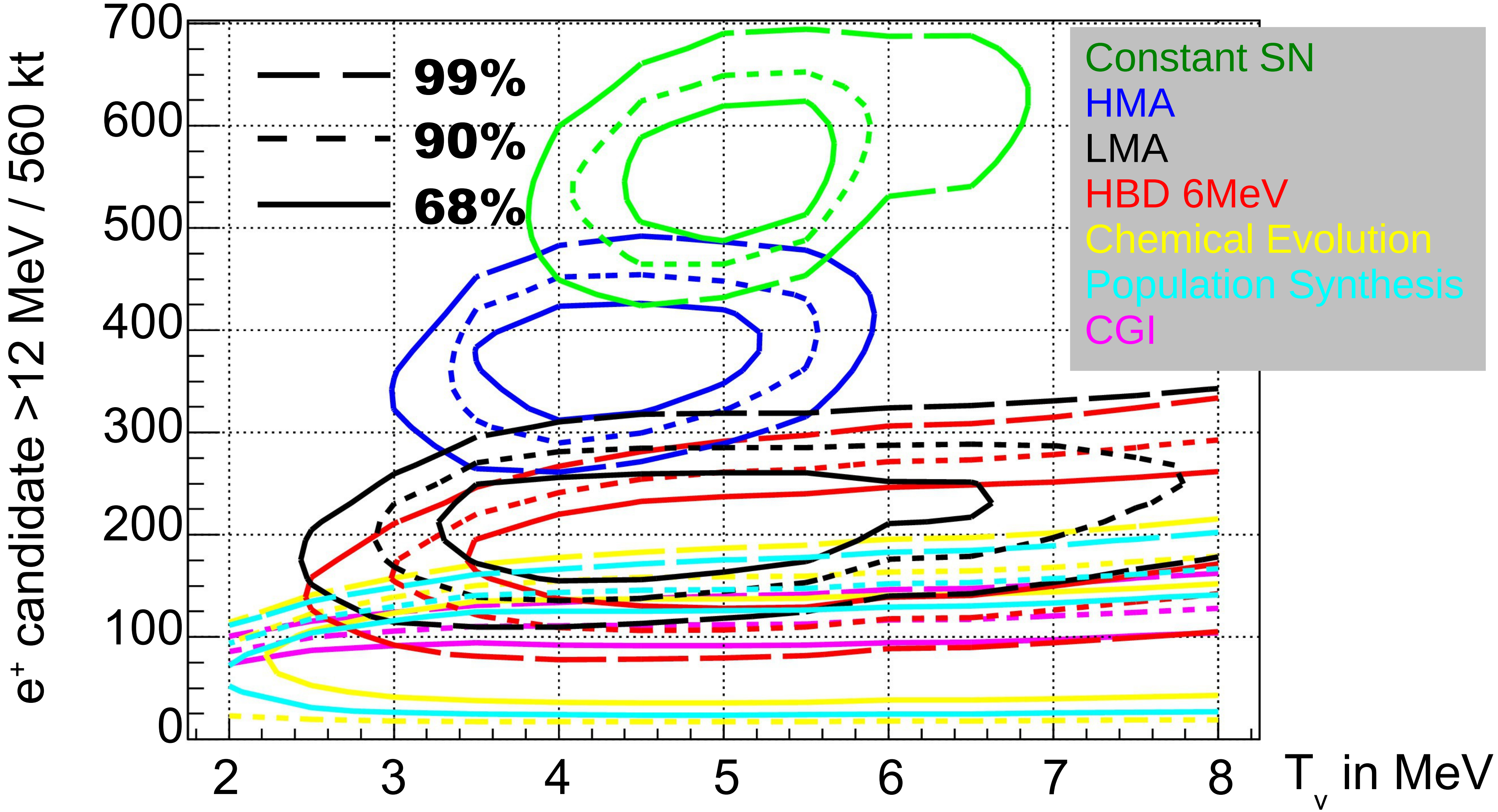
μ ×5, 10years HK



Separation between models is a bit worse than μ×2 case.
In summary, the difference of μ×1, 2 and 5 case does not affect SRN model Recognition dramatically.

SRN Model Recognition

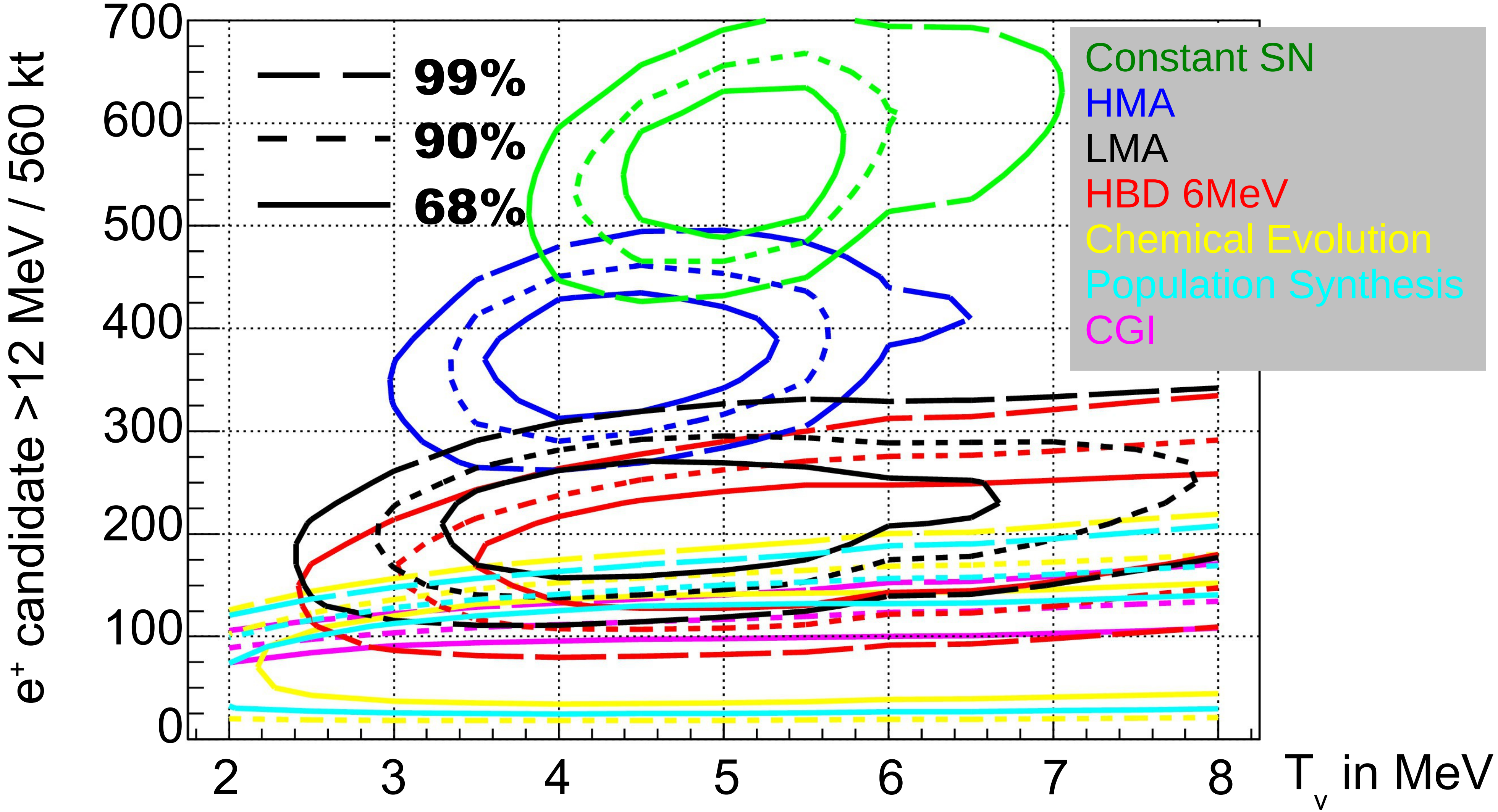
μ ×1, 10years HK



LMA can be distinguished from HMA, Constant SN or other models except for HBD 6MeV.
It would be difficult to distinguish LMA and HBD 6MeV.

SRN Model Recognition

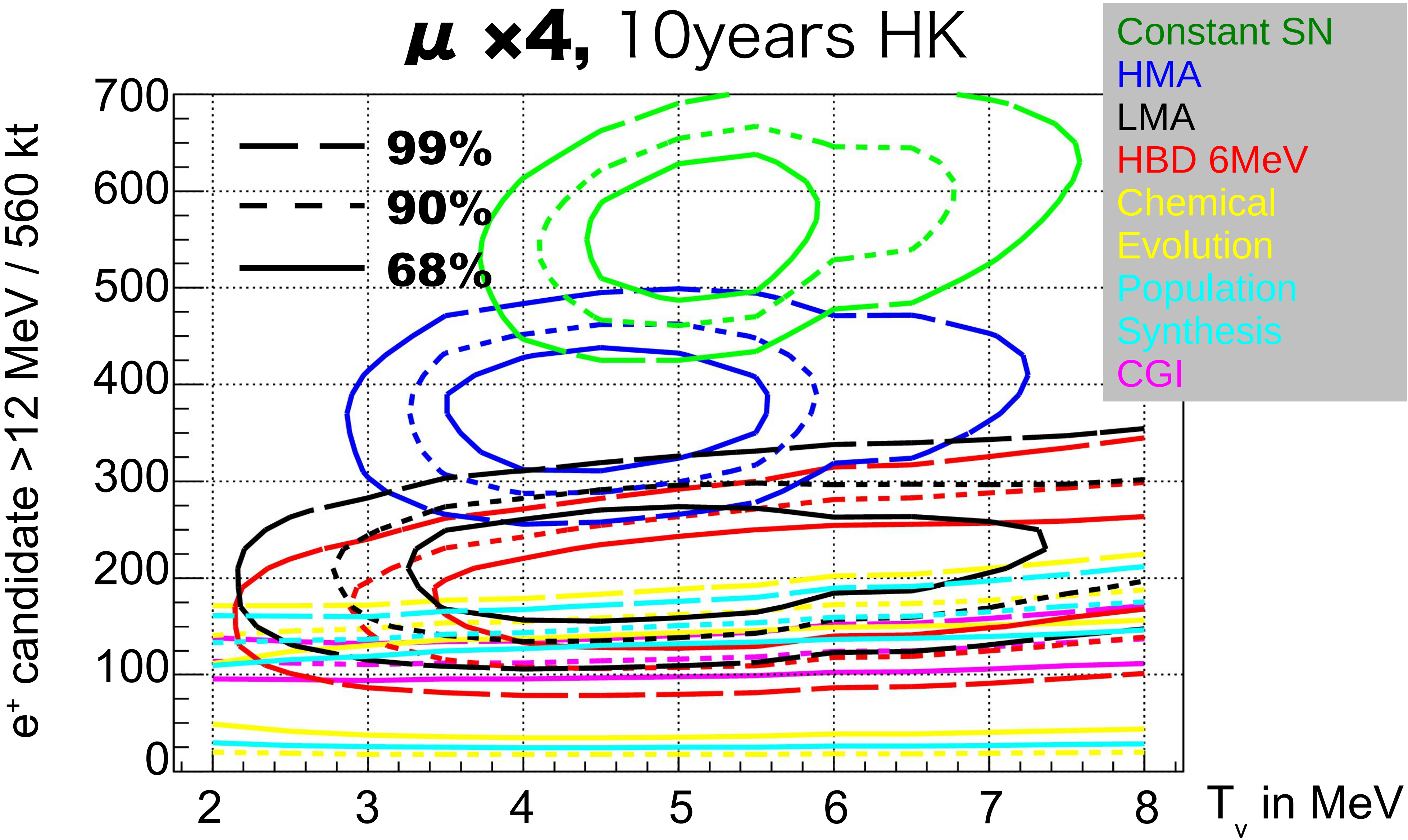
μ ×2, 10years HK



Separation between models is a bit worse than μ×1 case.

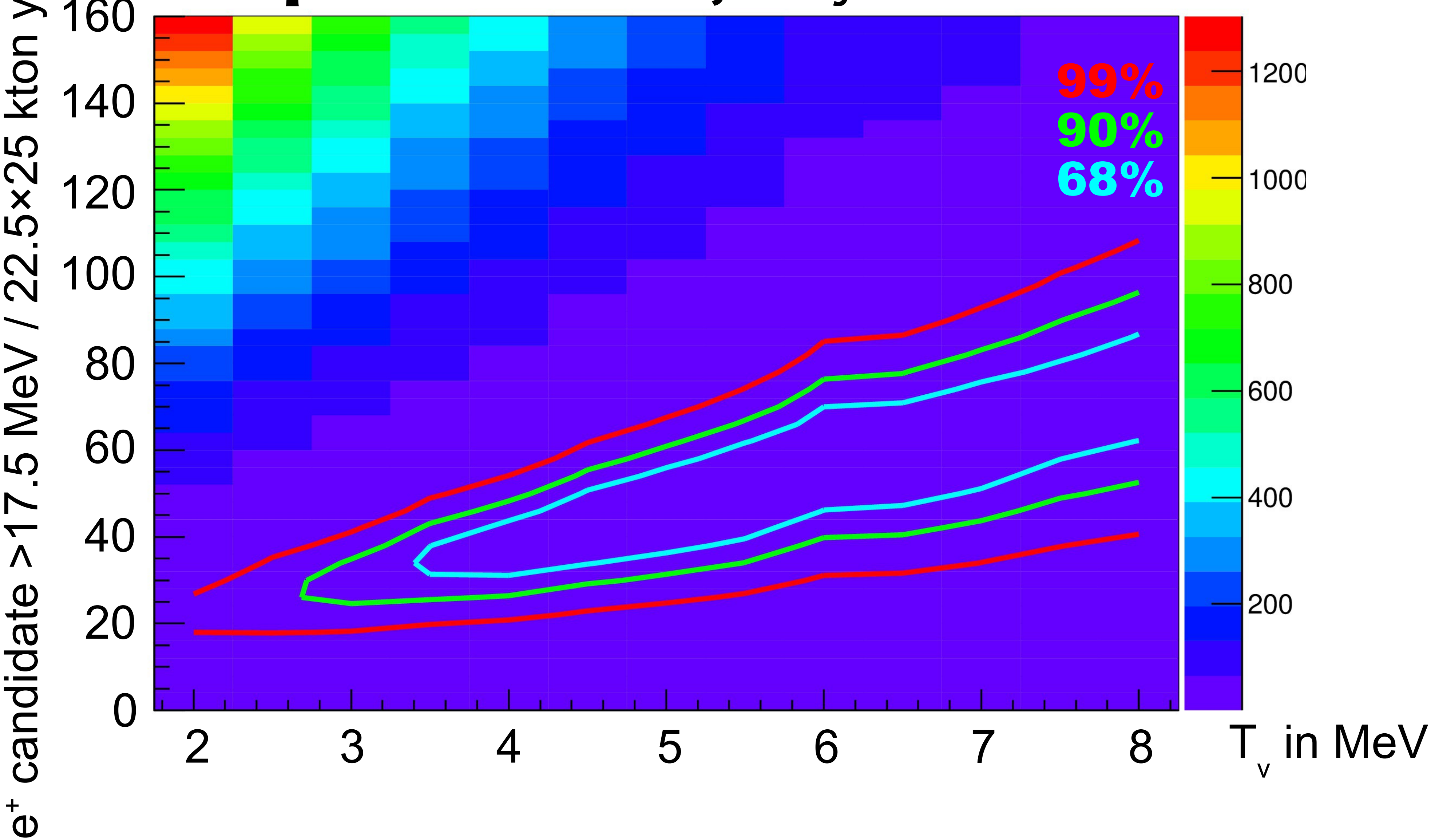
SRN Model Recognition

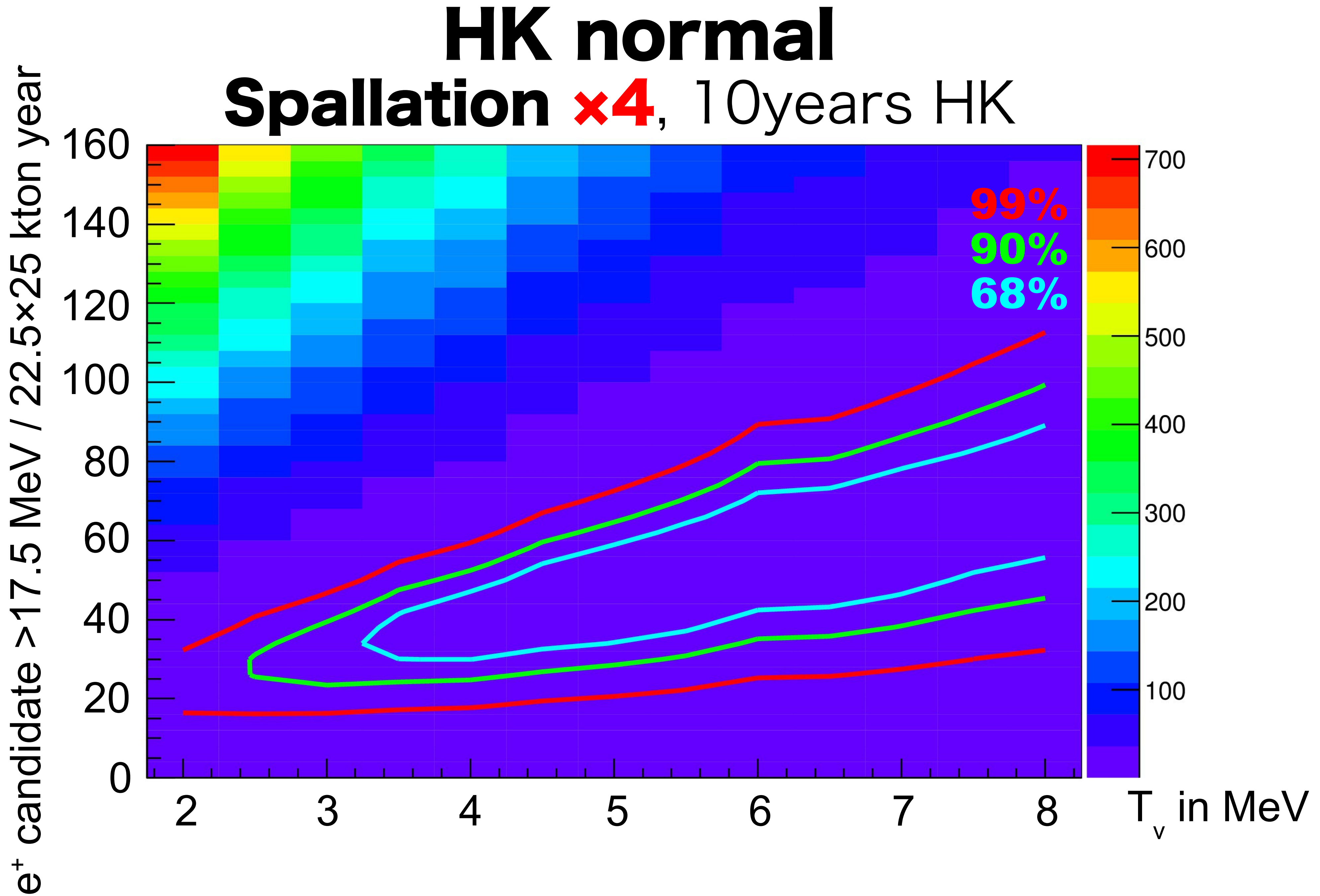
μ ×4, 10years HK



HK normal

Spallation ×1, 10years HK




HK normal
Spallation ×4, 10years HK
e+ candidate >17.5 MeV / 22.5×25 kton year
0
20
40
60
80
100
120
140
160
2
3
4
5
6
7
8
Tν in MeV
99%
90%
68%
100
200
300
400
500
600
700