Spallation Background

3rd Open Meeting for the Hyper-Kamiokande Project

June 21, 2013

I. Shimizu (Tohoku Univ.)

Motivation

Spallation is dominant background source in 10-20 MeV region

- Solar neutrino

potential to observe spectrum up-turn and day-night asymmetry

→ **Y. Koshio's study**

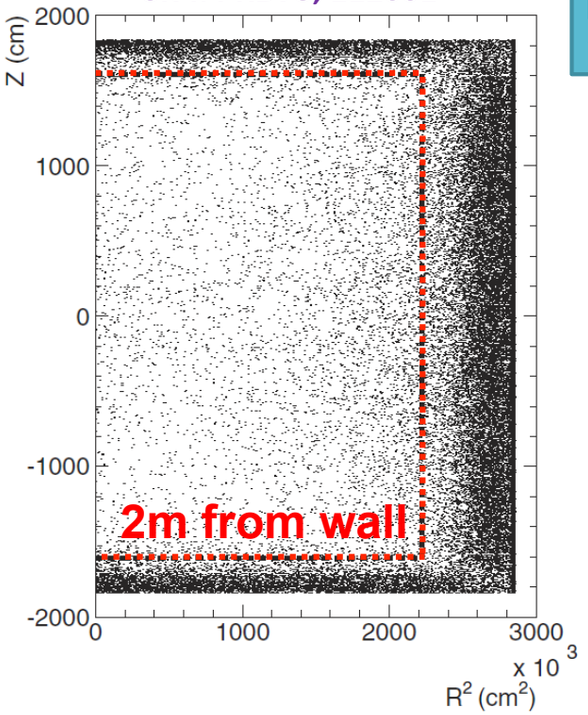
- Supernova relic neutrino

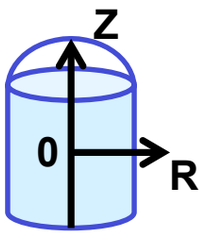
measure diffused neutrino flux and energy from supernovae >~Mpc

→ **T. Yano's study**

Low-e vertex dist.

SK-I: PRD73, 112001





Misfit

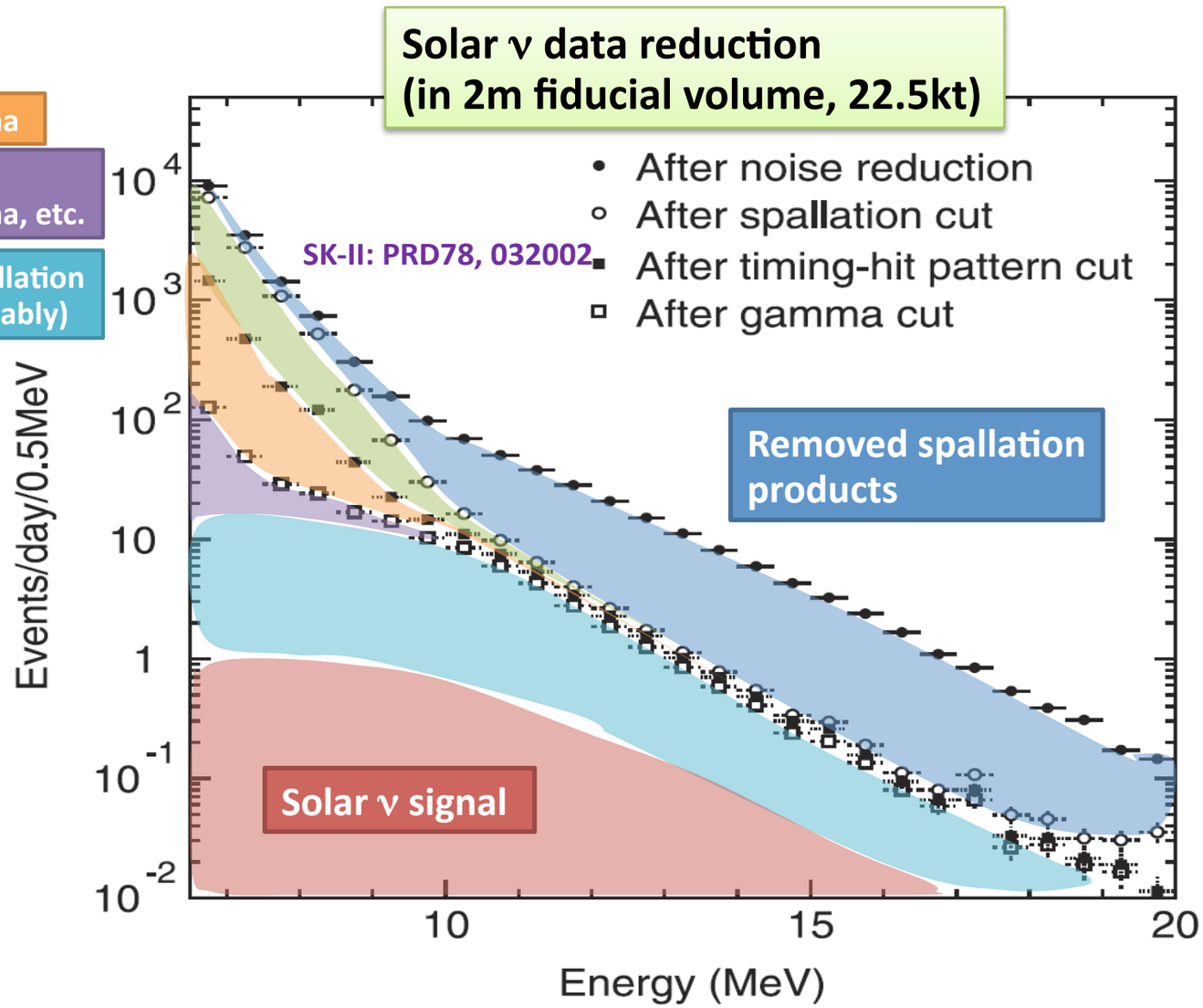
External gamma

Radon, Misfit, External gamma, etc.

Remaining spallation products (probably)

Solar ν data reduction (in 2m fiducial volume, 22.5kt)

SK-II: PRD78, 032002



Re-calculation of Muon Flux

(1) Provided HK position was incorrect and used for muon flux calculation in LOI ⟶ update

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**

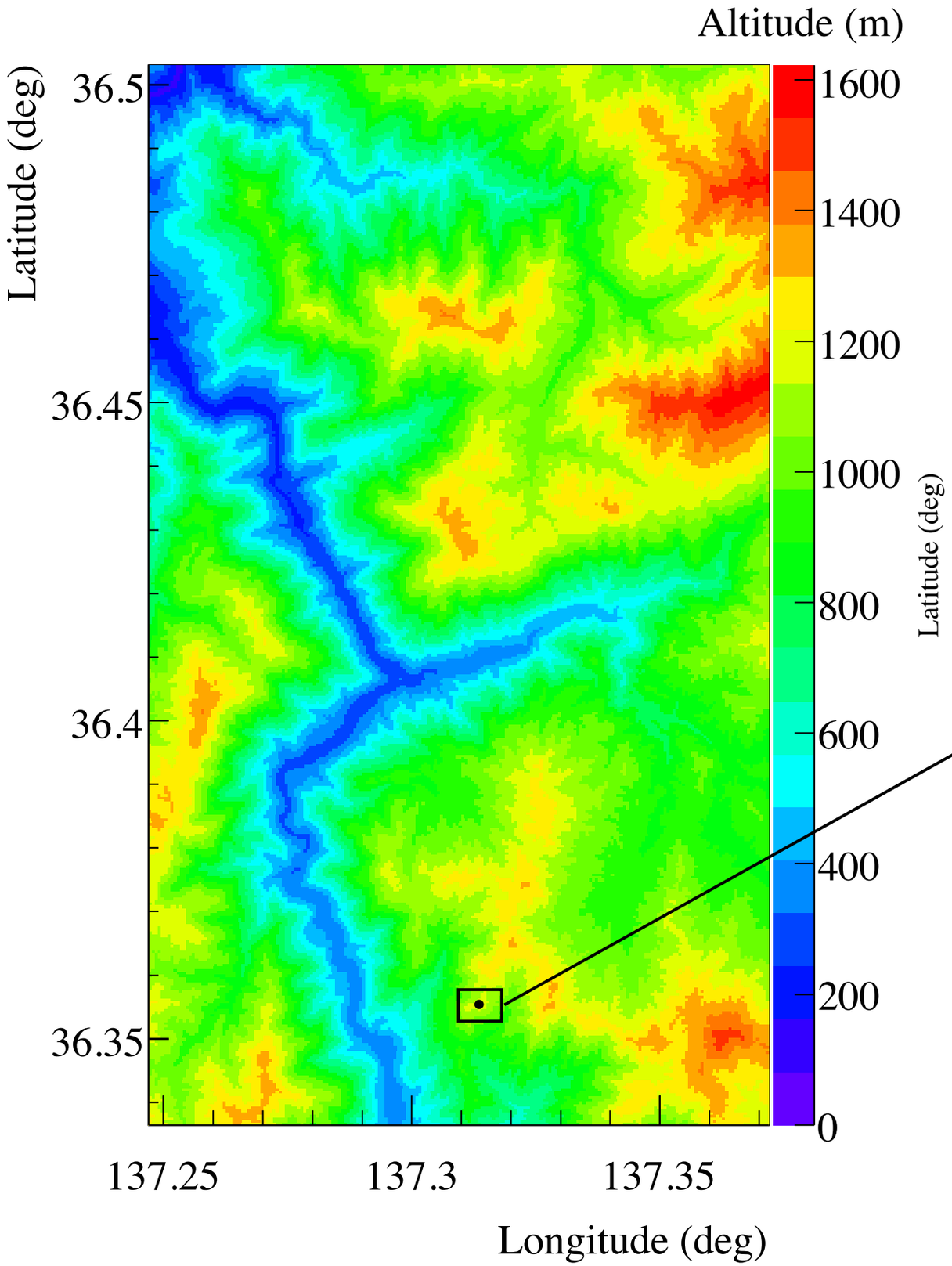
*Altitude of HK is 508 m

(2) Digital Elevation Data was newly provided by Geospatial Information Authority of Japan ⟶ update

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

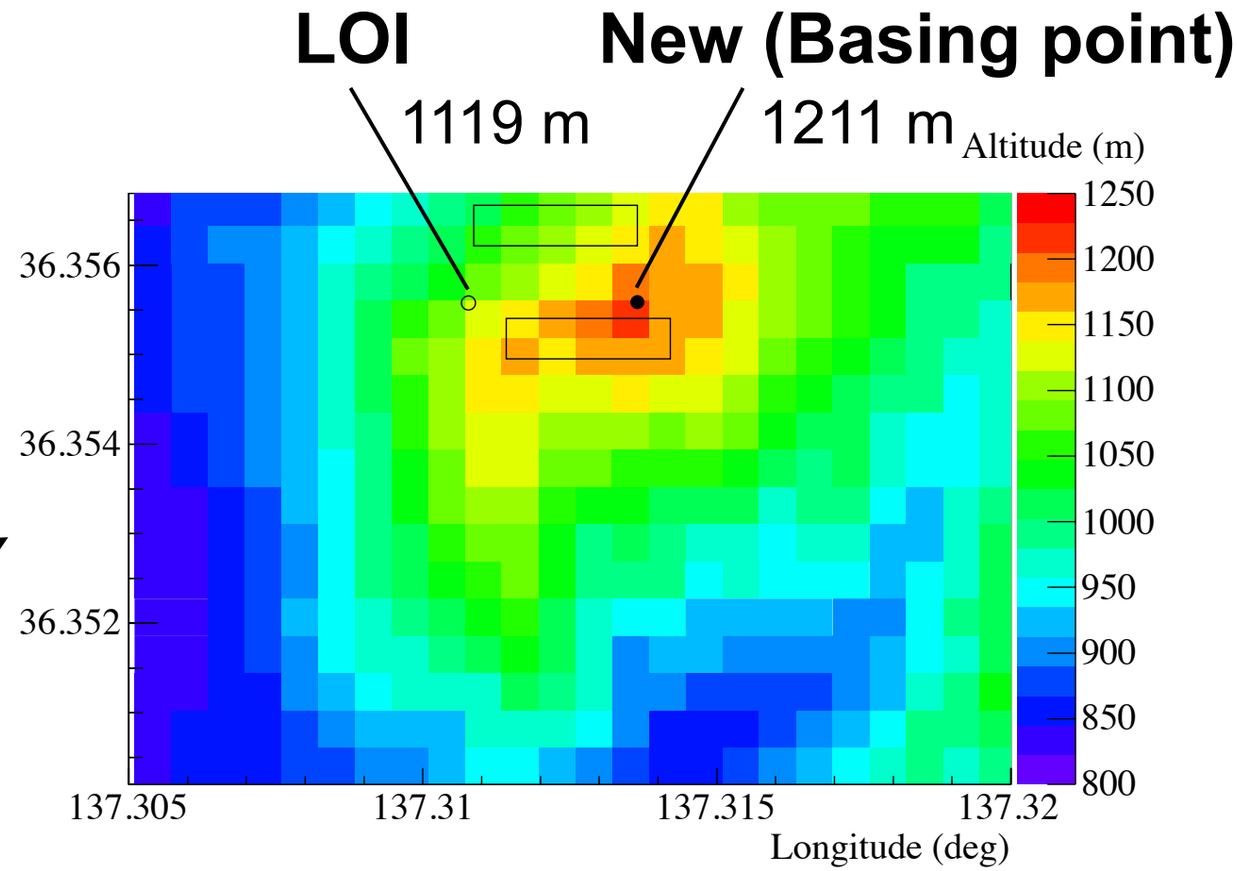
*New data has the decrease of peak elevation (~ 100 m) after surface mining

Digital Elevation Data around HK



Elevation data (**50 m mesh, 1970**) around peak of Mt. Nijyugo-yama

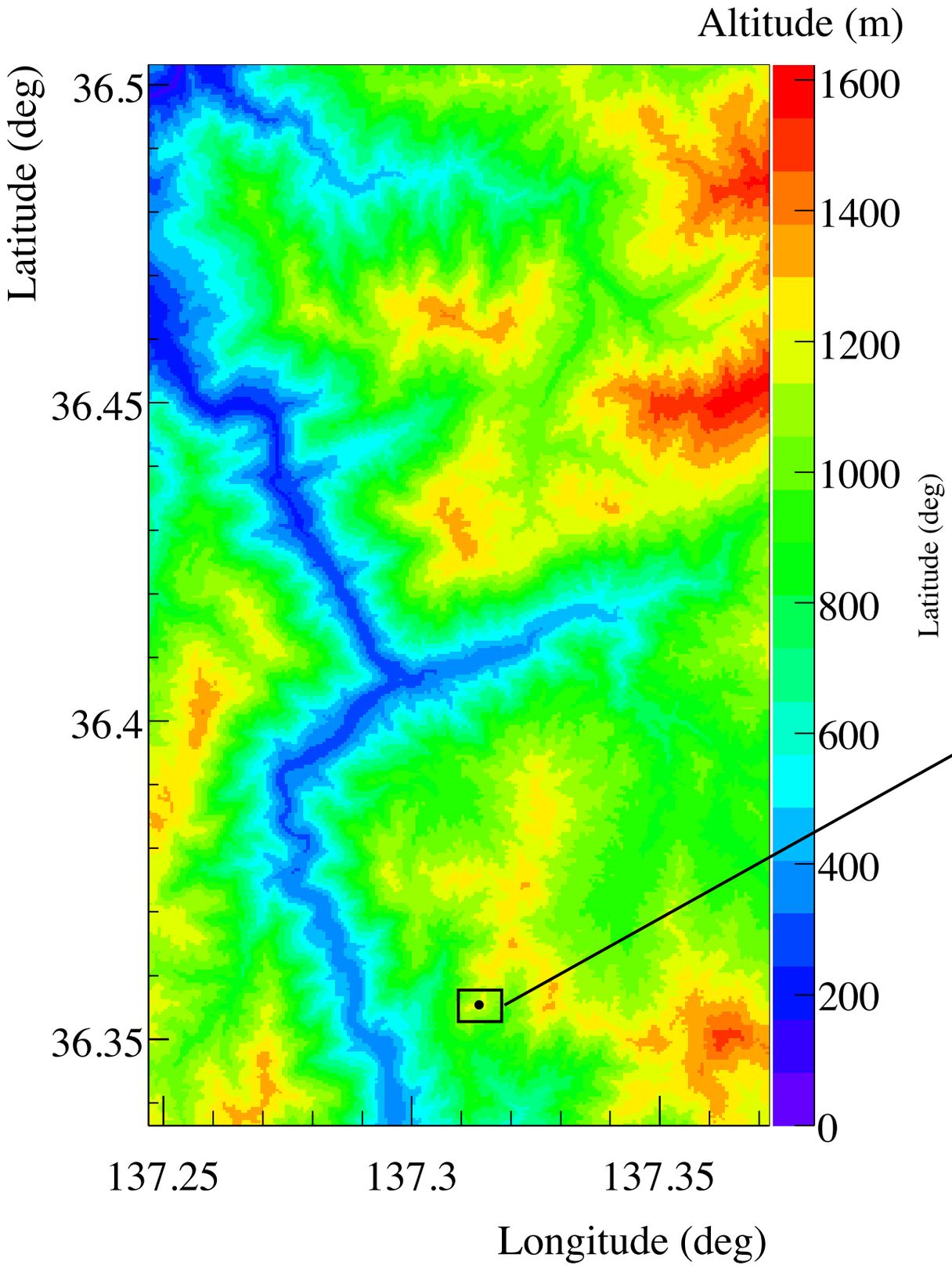
HK position



Peak 1211 m

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

Digital Elevation Data around HK



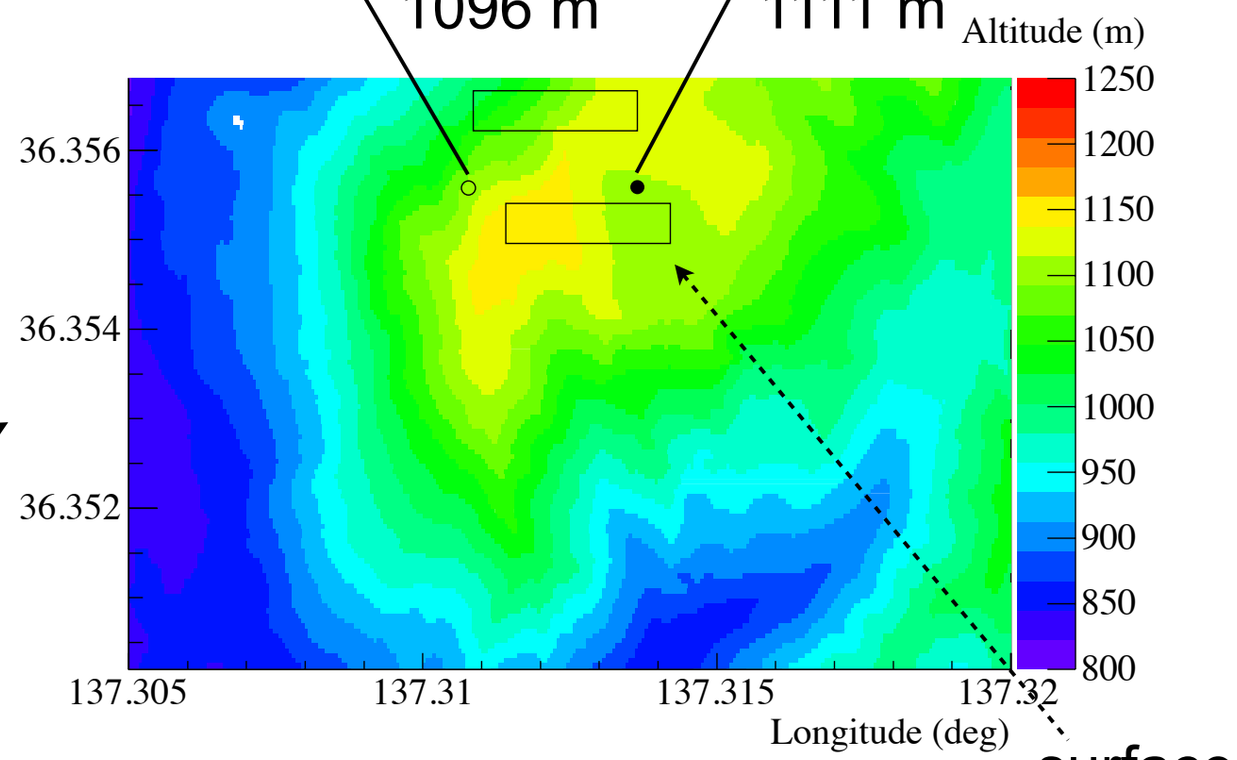
Elevation data (**5 m mesh, 2010**)

around peak of Mt. Nijyugo-yama

HK position

LOI 1096 m

New (Basing point) 1111 m



surface mining

Peak 1155 m

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

Muon Simulation Tool

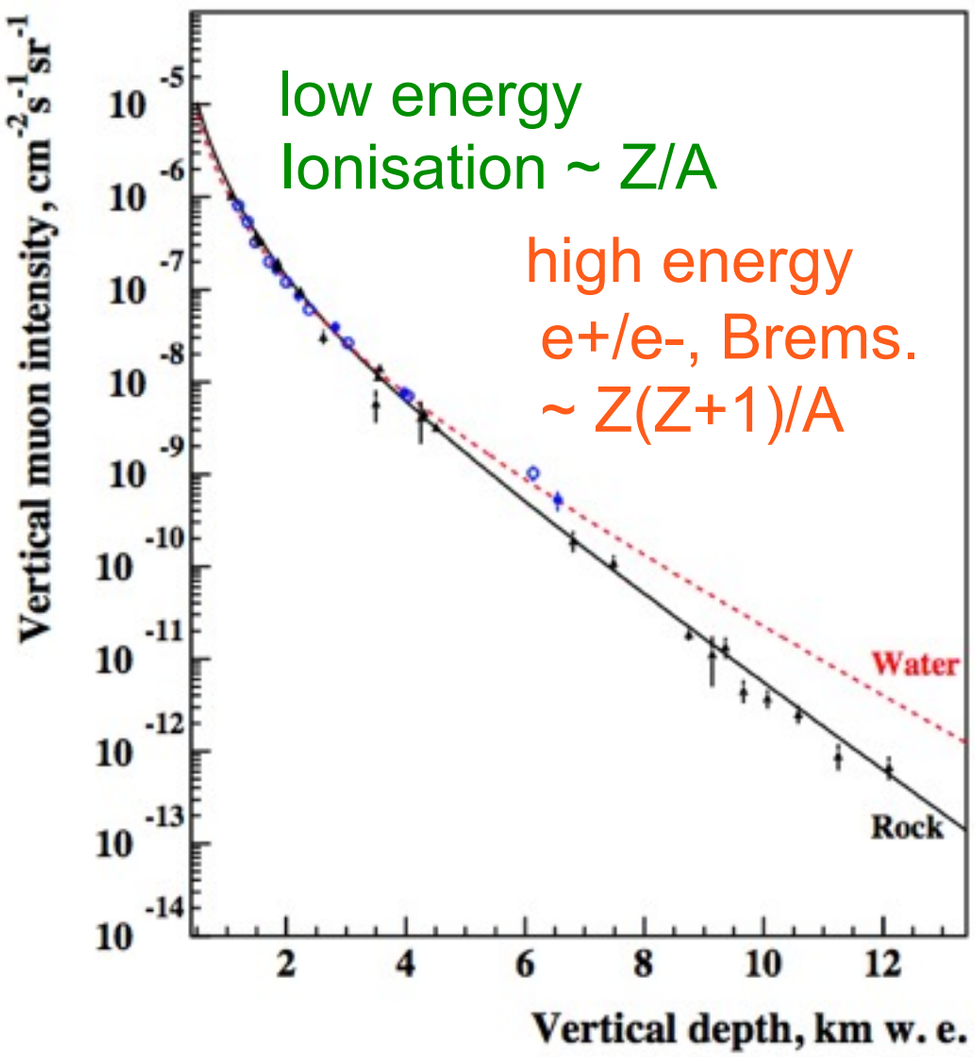
MUSIC (MUon SImulation Code) **V.A. Kudryavtsev, arXiv:0810.4635**

3D MC tool dedicated to muon transportation in matter

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

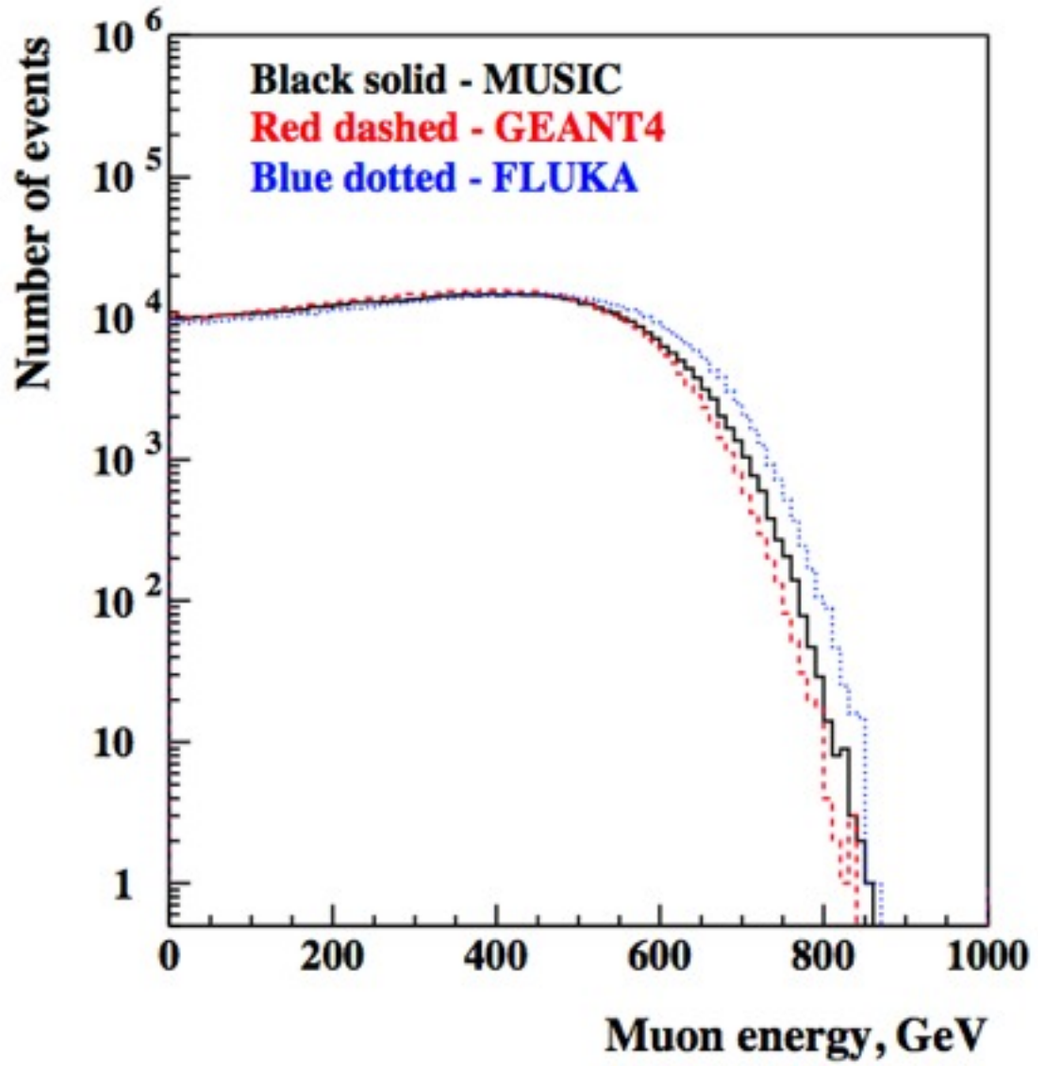
V.A. Kudryavtsev, arXiv:0810.4635

vertical muon flux



muon energy

(2 TeV transported through 3 km water)



Rock Density and Composition

Rock composition at HK is similar to that at SK (“skarn” type deposit)

→ Use evaluated simulation uncertainty at KamLAND (close to SK)

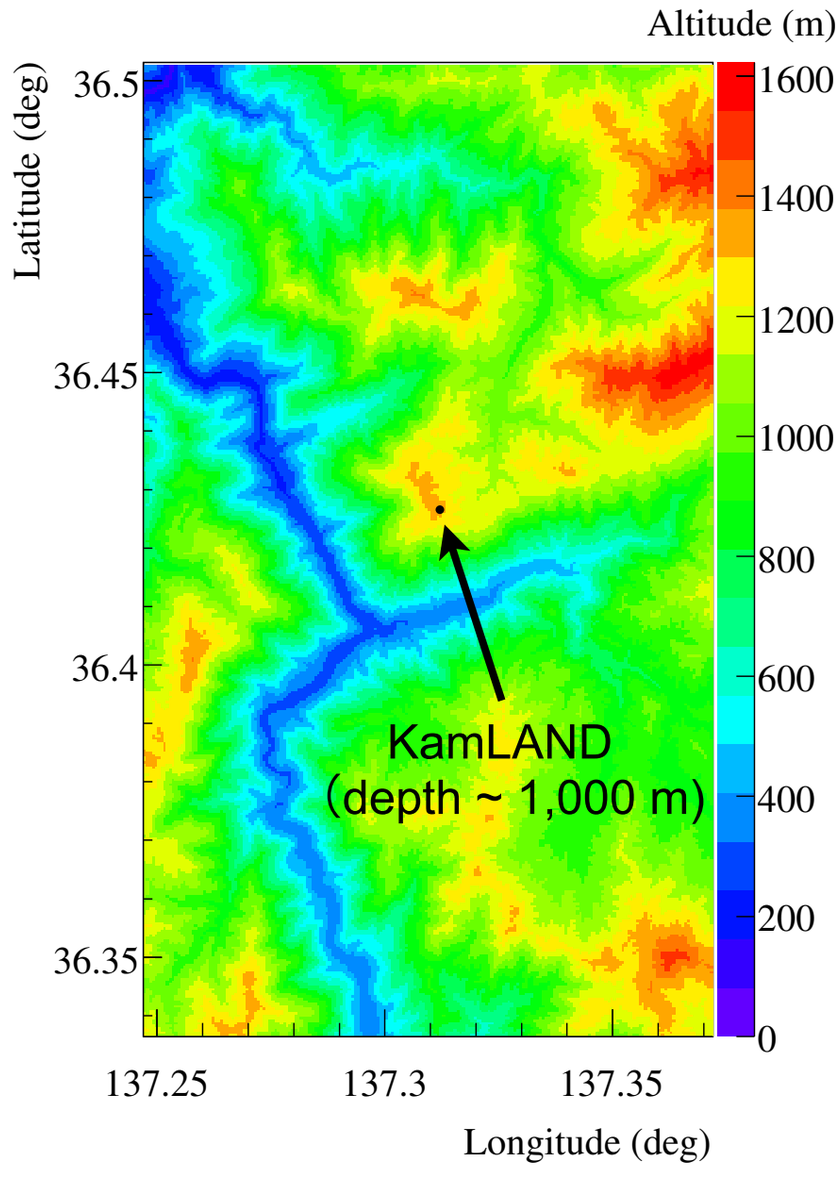
simulation condition

Surface muon flux	Modified Gaisser model A. Tang et a., arXiv:hep-ph/0604078
Rock type	Several Ikenoyama rock
Typical rock density	2.65 ~ 2.75 g/cm^{-3}

muon flux and energy @ KamLAND

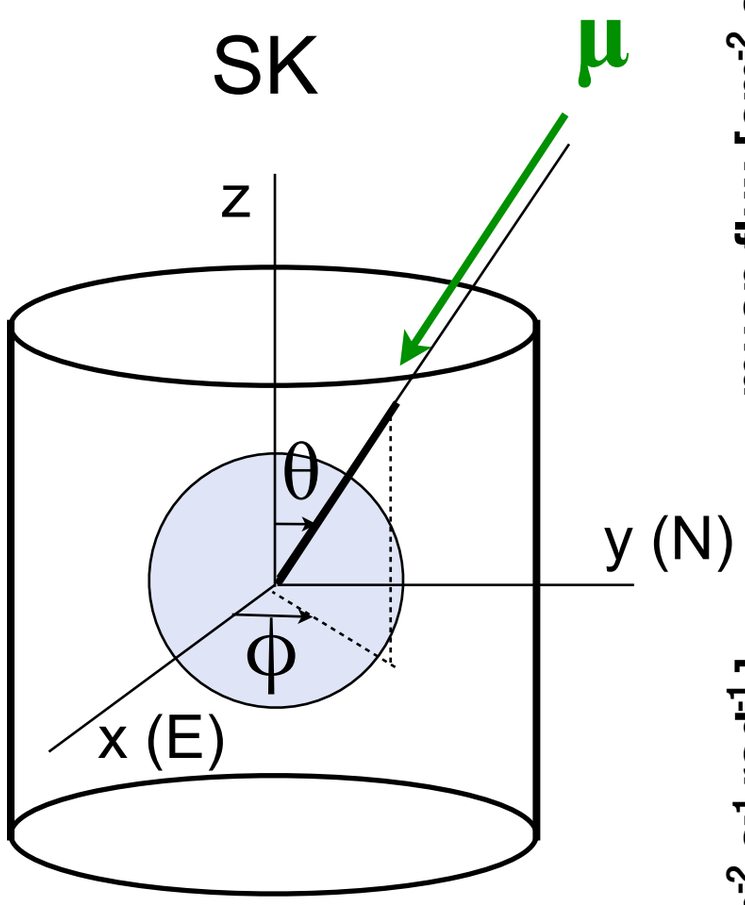
	J_μ (m^{-2} h^{-1})	E_μ (GeV)
Inishi rock	5.66 ~ 6.71	262 ~ 268
Standard rock	4.95 ~ 5.83	256 ~ 262
Generic skarn	4.90 ~ 5.82	254 ~ 260
Measurement	5.37 ± 0.41	—

S. Abe et al., PRC81, 025807 (2010)

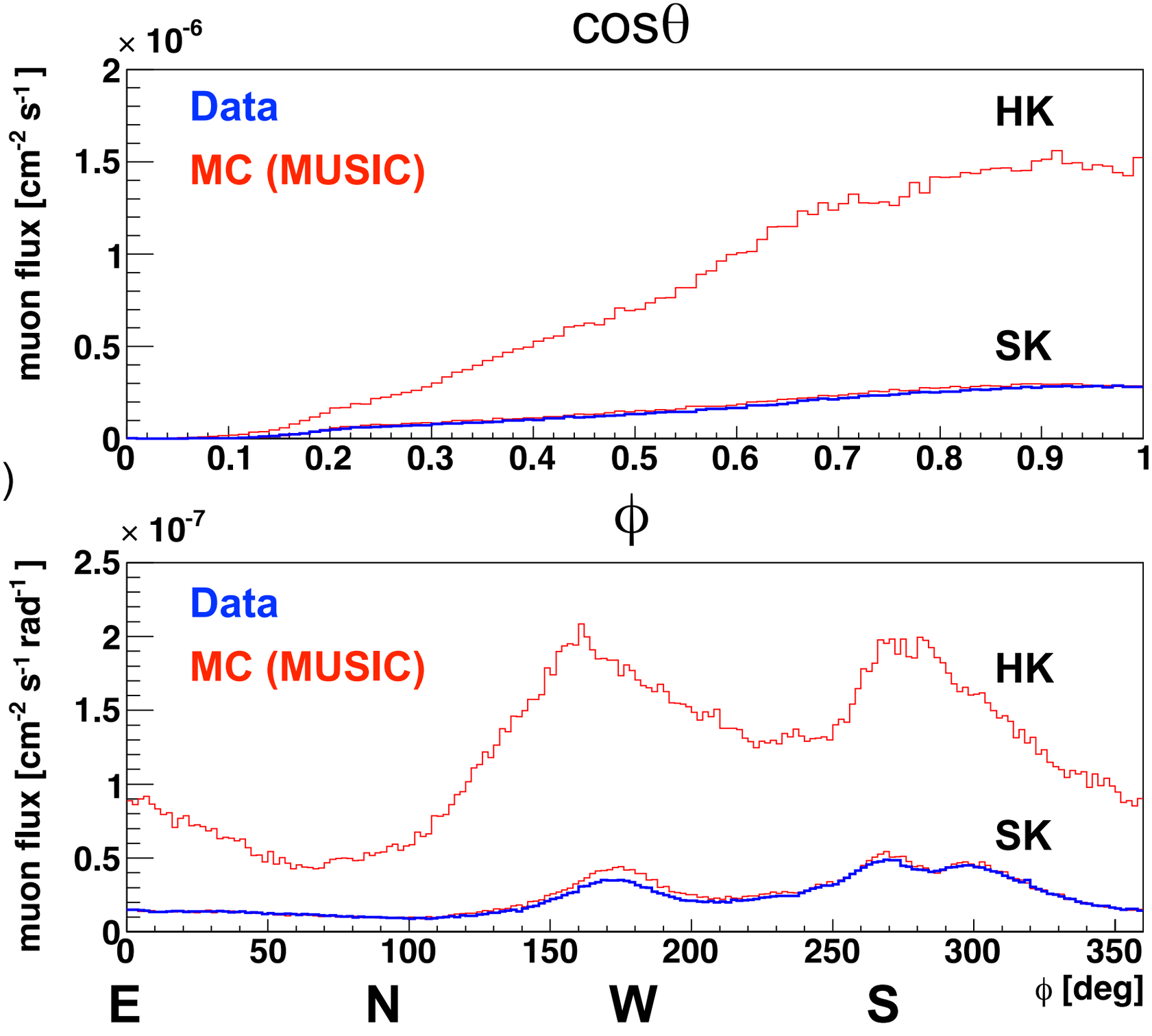


- Muon flux uncertainty from rock density and composition ~ ±20%
- Average muon energy 260 ± 8 GeV

Comparison of Muon Flux at HK / SK



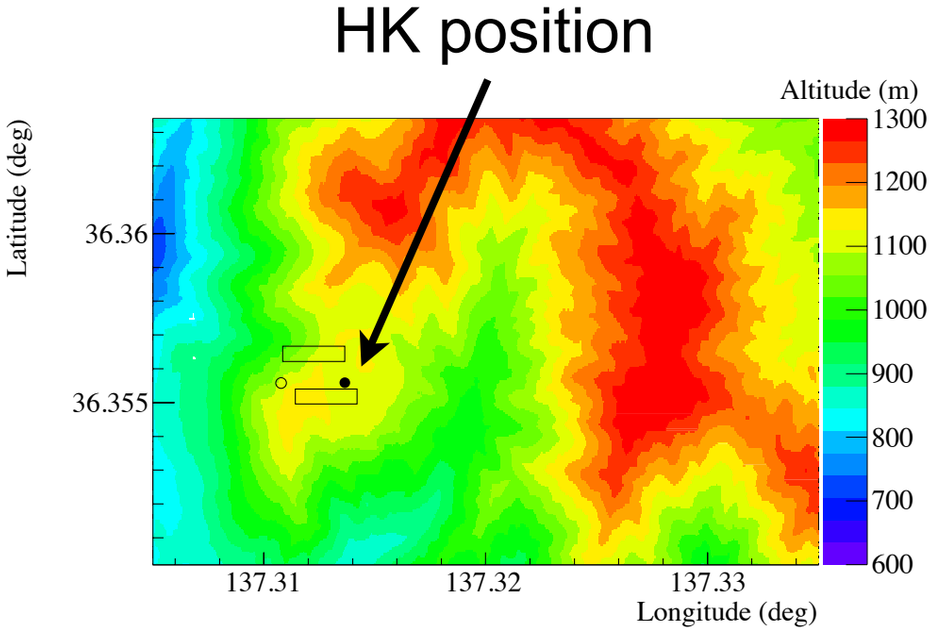
muon flux measurement
with 12 day data
in spherical volume
(R = 10 m)



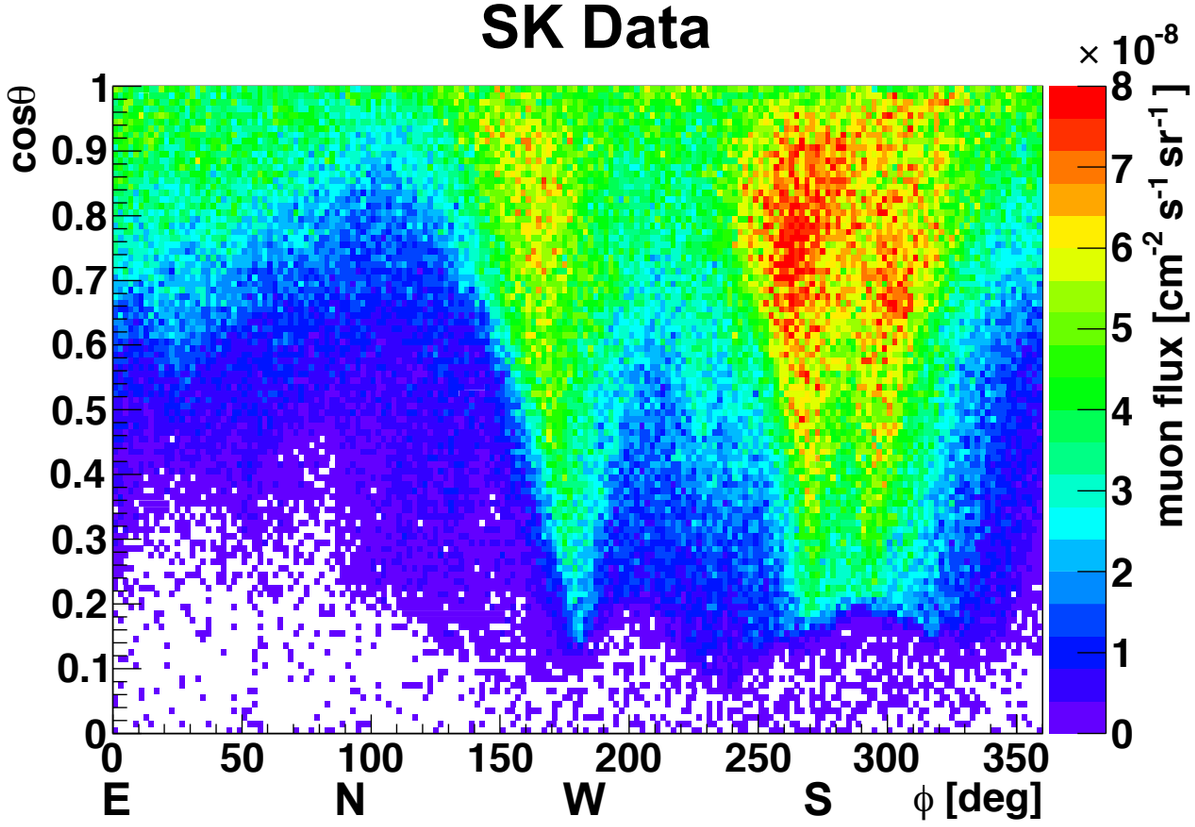
Ratio of total muon flux (HK / SK) = **4.90 ± 0.98***

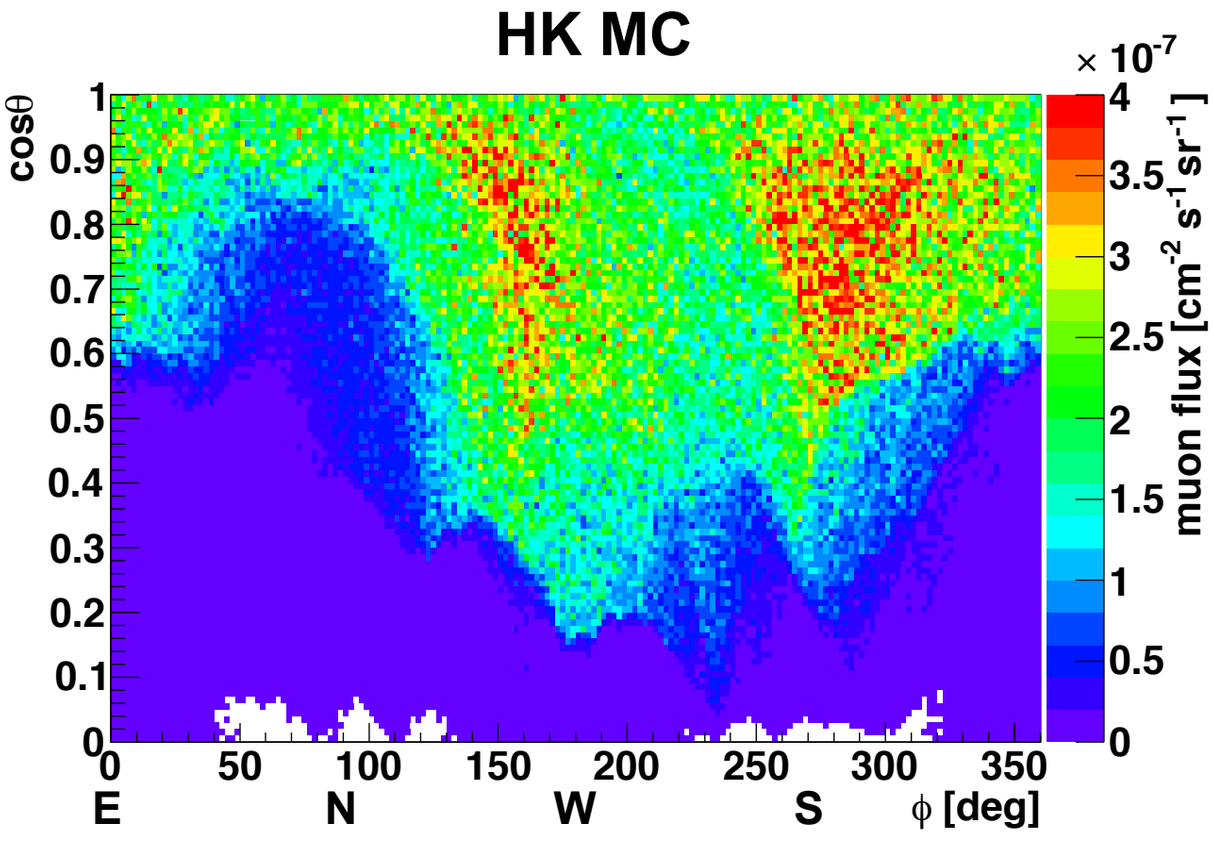
***flux at HK basing point**

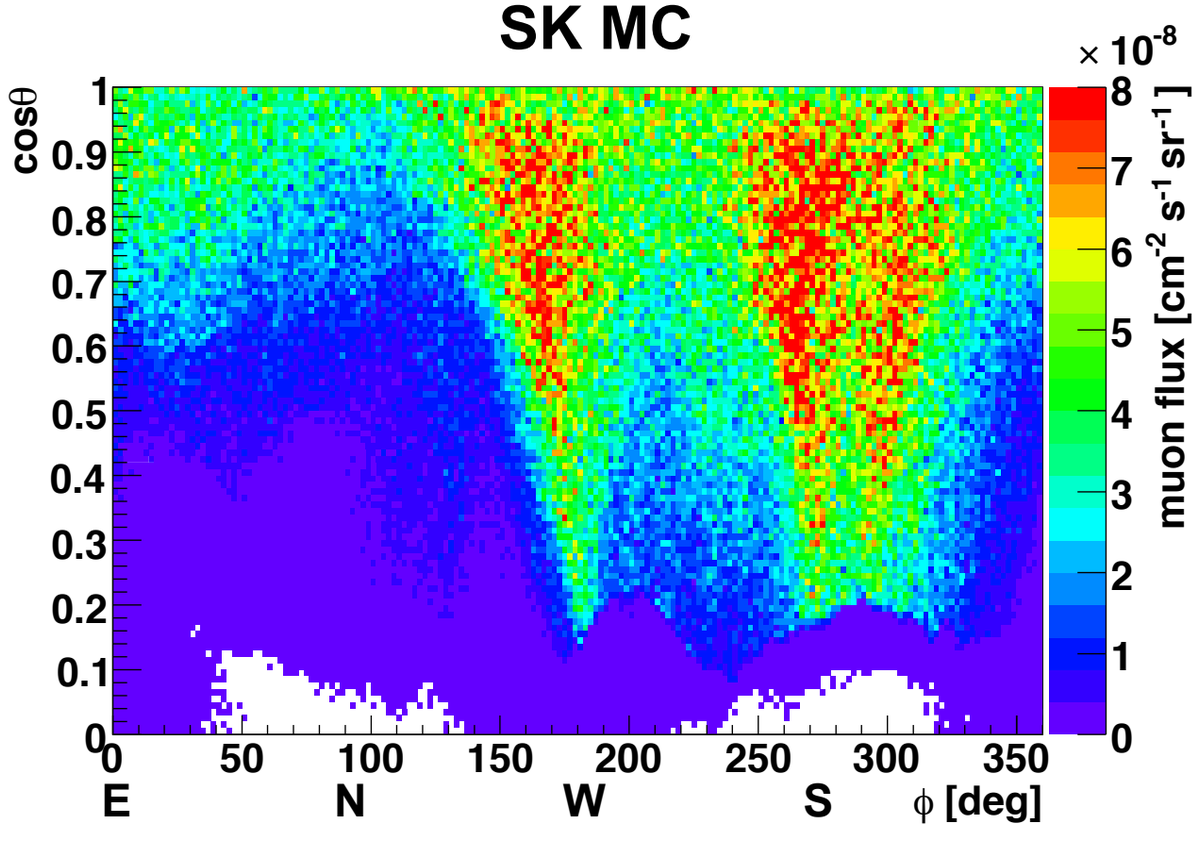
cosθ v.s. ϕ at HK / SK



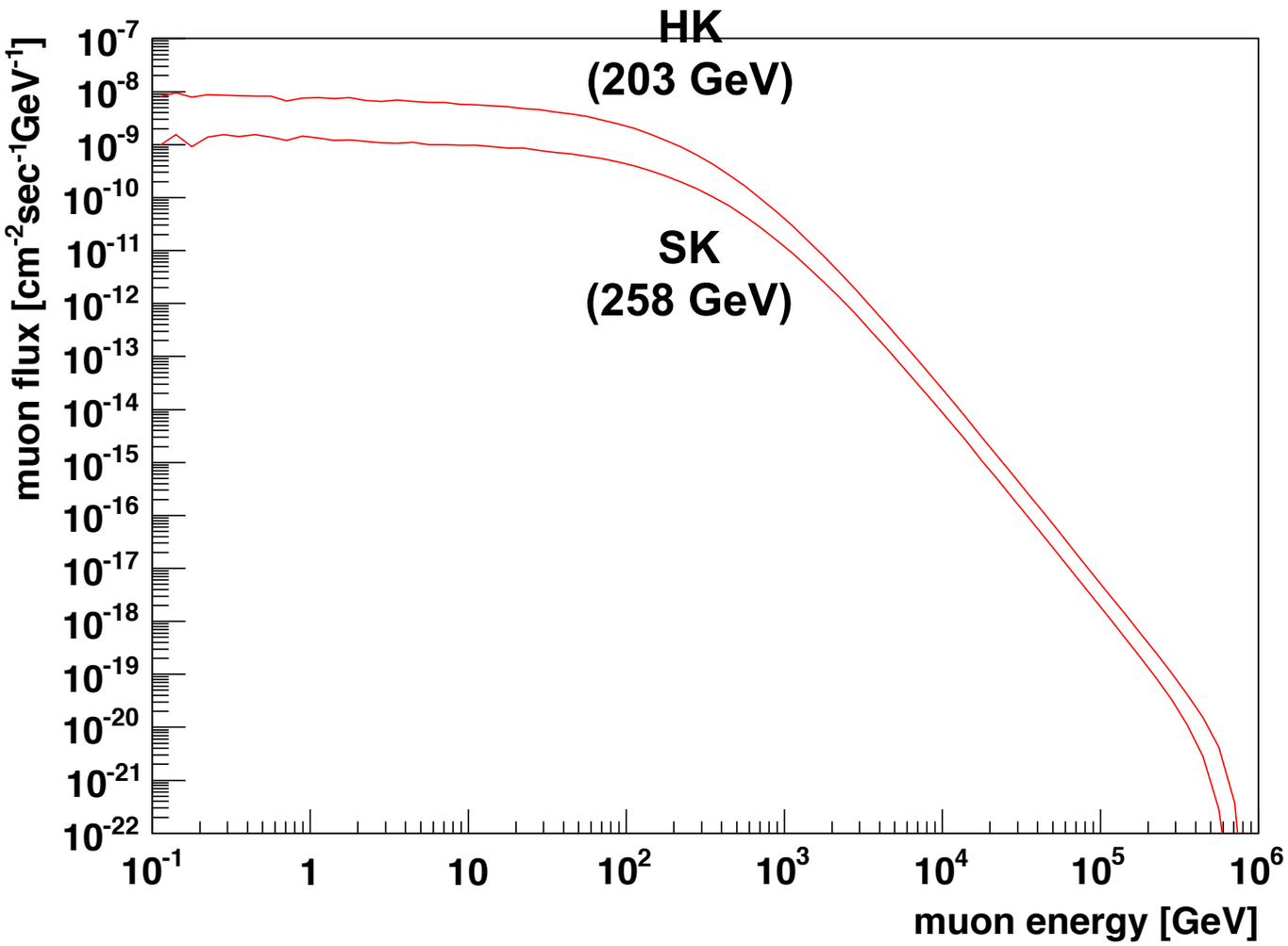
shallower in the west and south







Muon Energy Spectrum at HK / SK



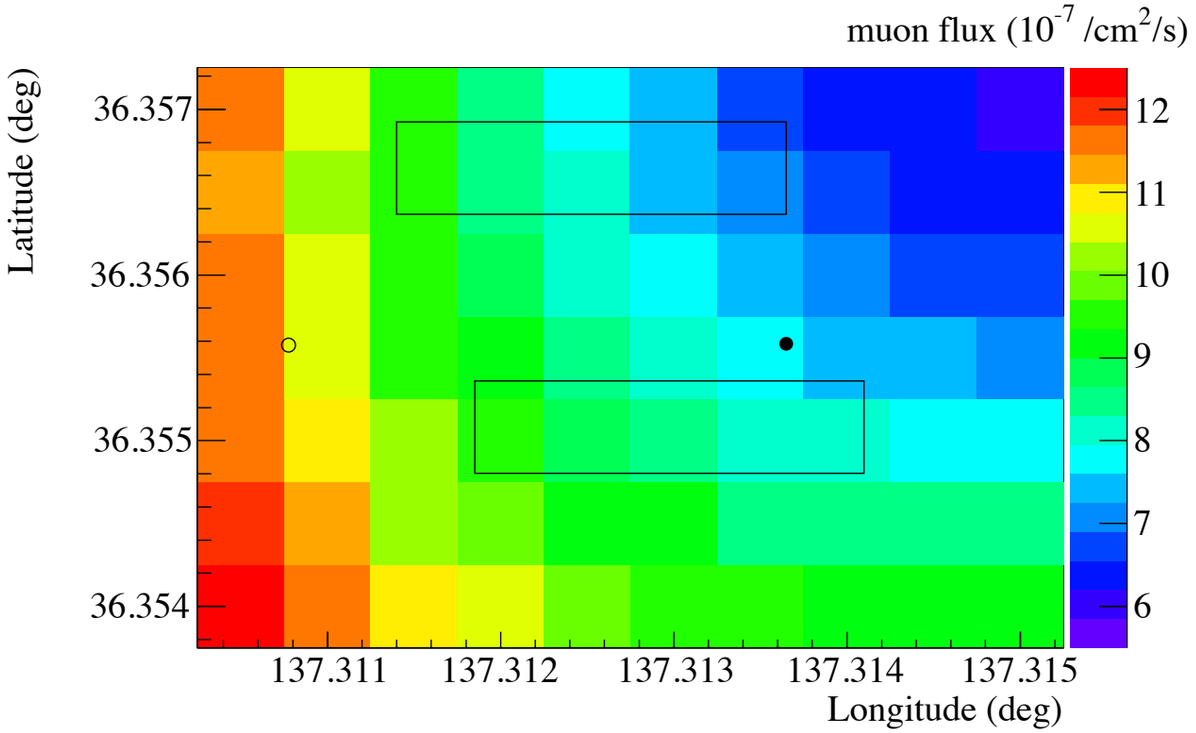
Summary of MC (MUSIC)

	HK	SK
muon flux	**7.55 x 10^{-7} $cm^{-2}s^{-1}$**	**1.54 x 10^{-7} $cm^{-2}s^{-1}$**
muon average energy	**203 GeV**	**258 GeV**

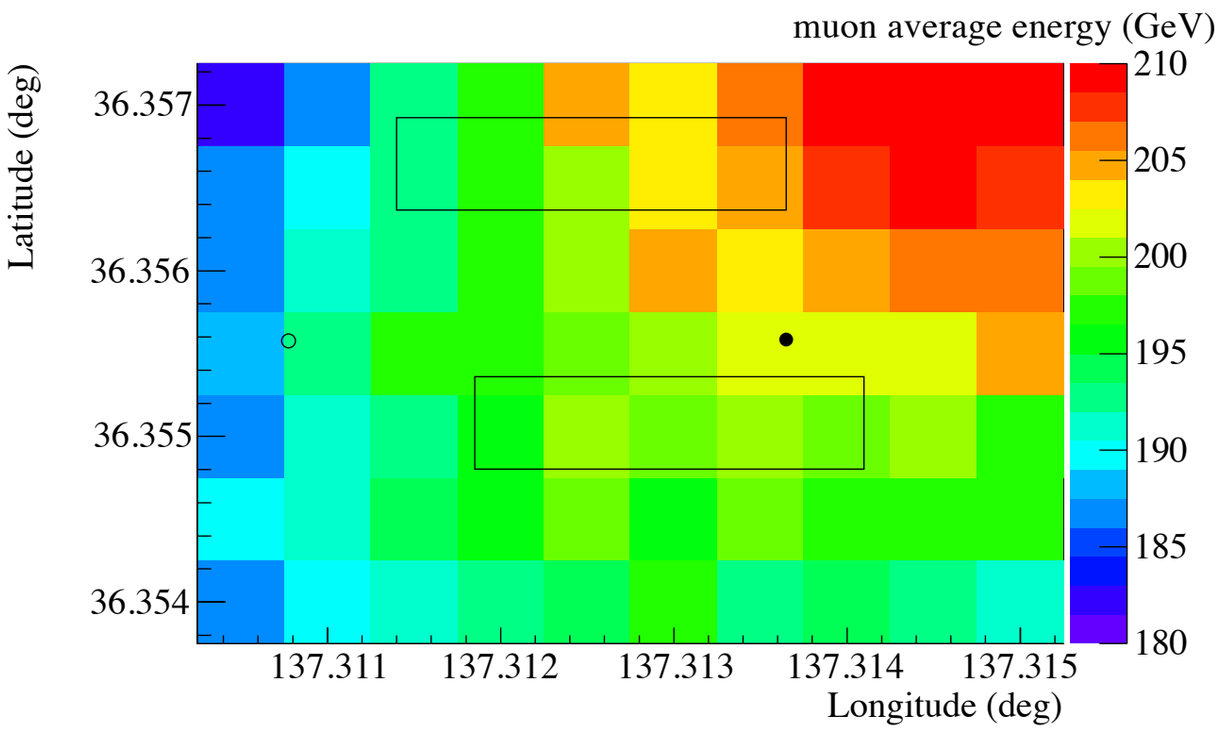
Energy spectra are used for muon spallation simulation

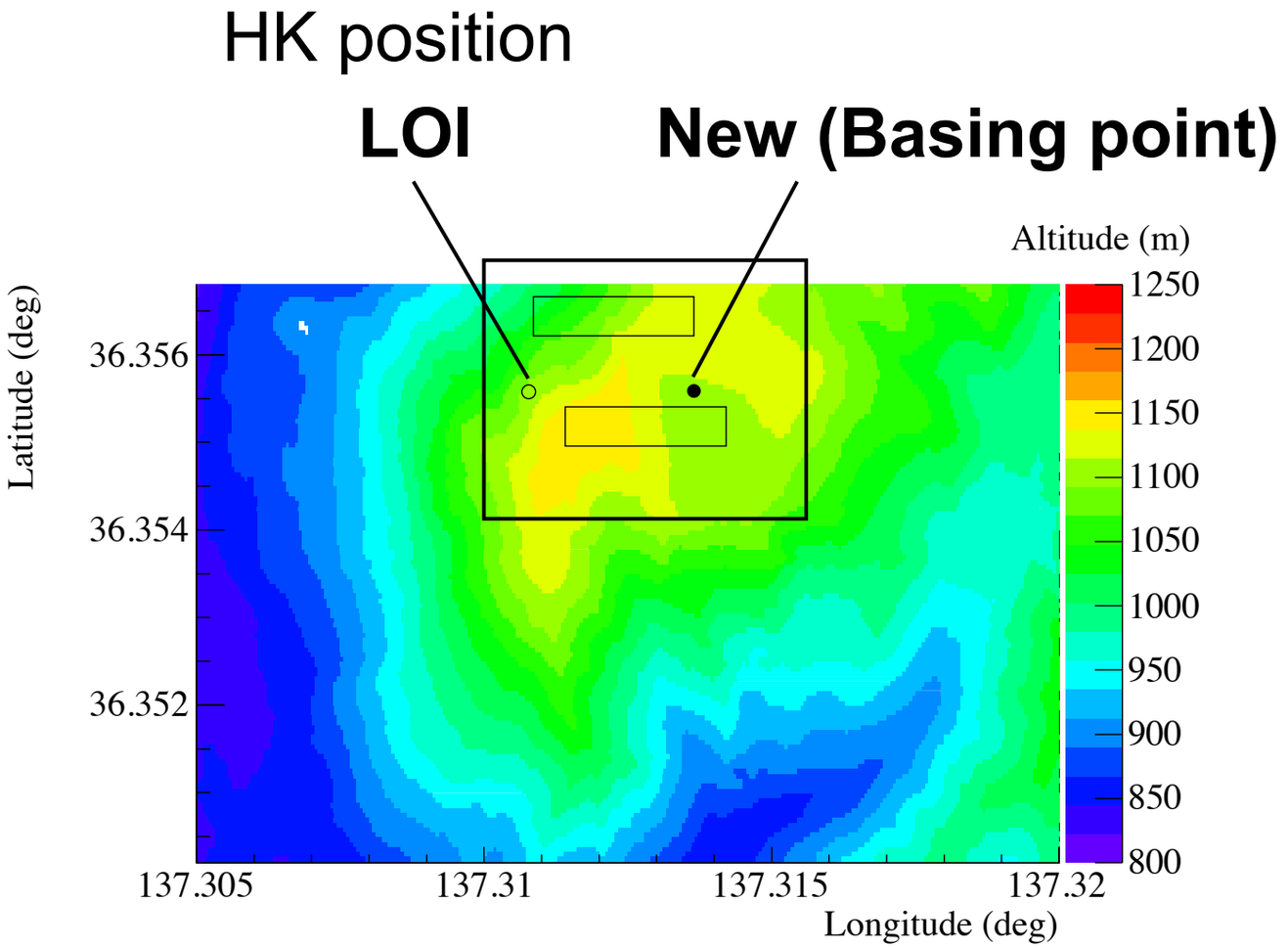
Muon Simulation around HK

muon flux



muon average energy





shallower in the west and south

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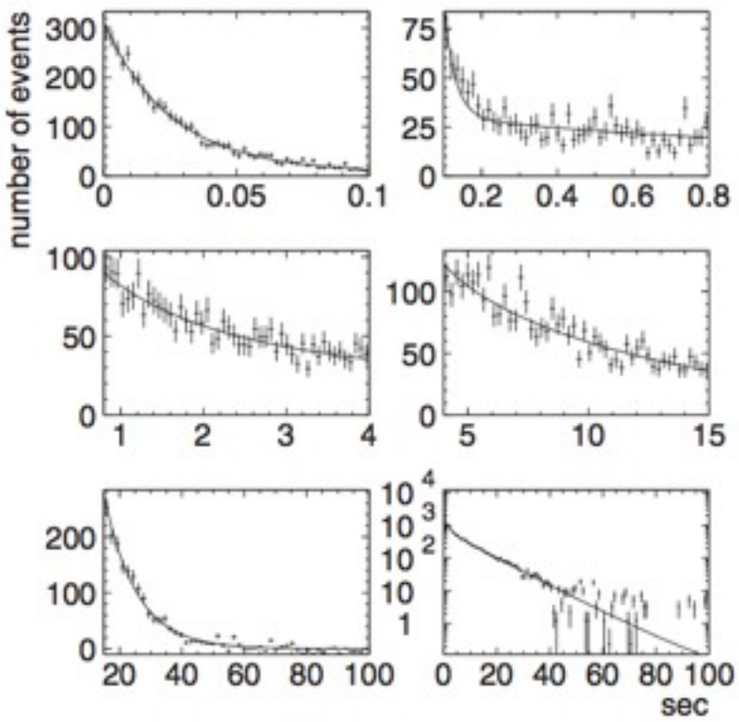
higher flux and lower energy

Estimation of Isotope Yield

Rate at SK from time correlation between muon and low energy event

J. Hosaka et al., PRC73, 112001 (2006)

ΔT distribution



isotope production rate

i	Radioactivity	$\tau^i_{1/2}$	A_i
1	$^{12}_{5}$B	2.02×10^{-2}	1.20×10^{5}
2	$^{12}_{7}$N	1.10×10^{-2}	3.39×10^{4}
3	$^{9}_{3}$Li	1.78×10^{-1}	3.39×10^{2}
4	$^{8}_{3}$Li	8.40×10^{-1}	1.25×10^{3}
5	$^{15}_{6}$C	2.45	1.35×10^{2}
6	$^{16}_{7}$N	7.13	6.76×10^{2}
7	$^{11}_{4}$Be	13.83	7.79

Rate at HK

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

Rate (SK): Data

$\frac{\Phi(HK)}{\Phi(SK)}$: MC (MUSIC)

$\frac{Y(HK)}{Y(SK)}$: MC (FLUKA)

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

(muon energy dependent)

Muon Spallation MC

FLUKA general purpose MC tool for particle transport and interactions

Spallation MC by FLUKA using muon energy spectrum at HK / SK

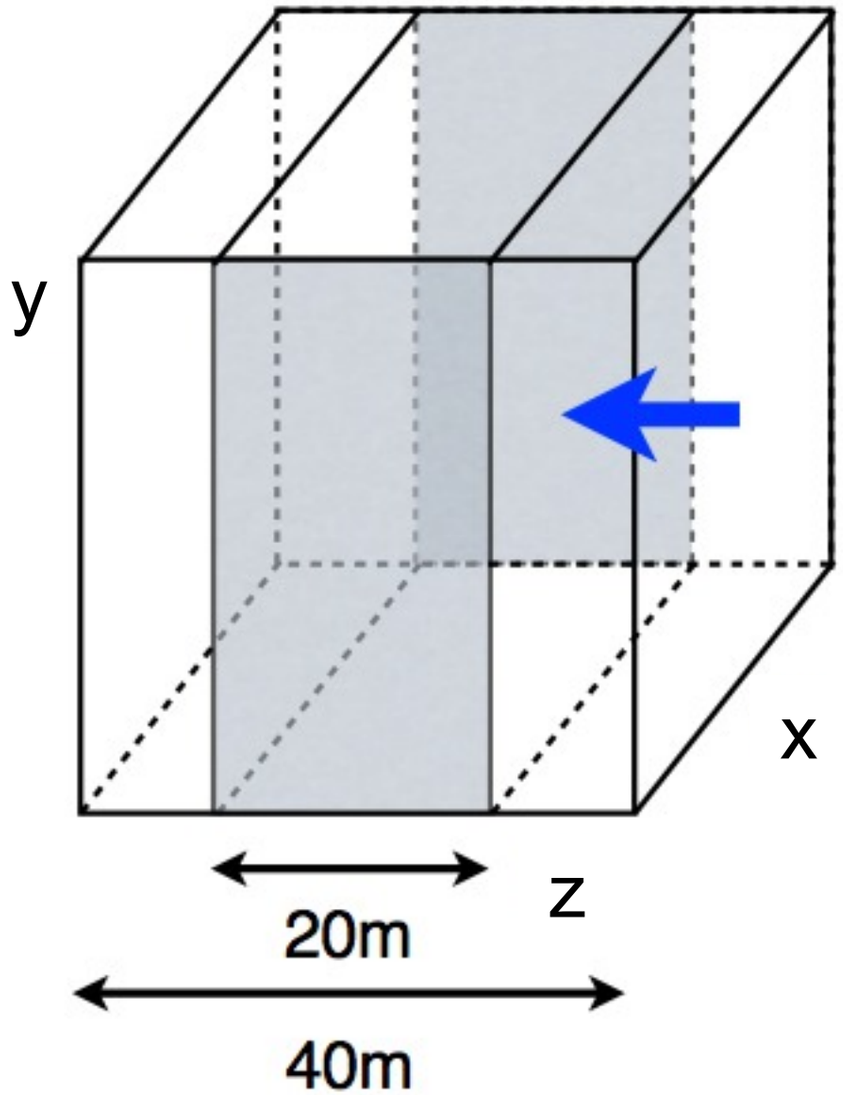
simulation condition

muon energy spectrum: MUSIC MC

target: water

FLUKA: version 2011.2b (latest)

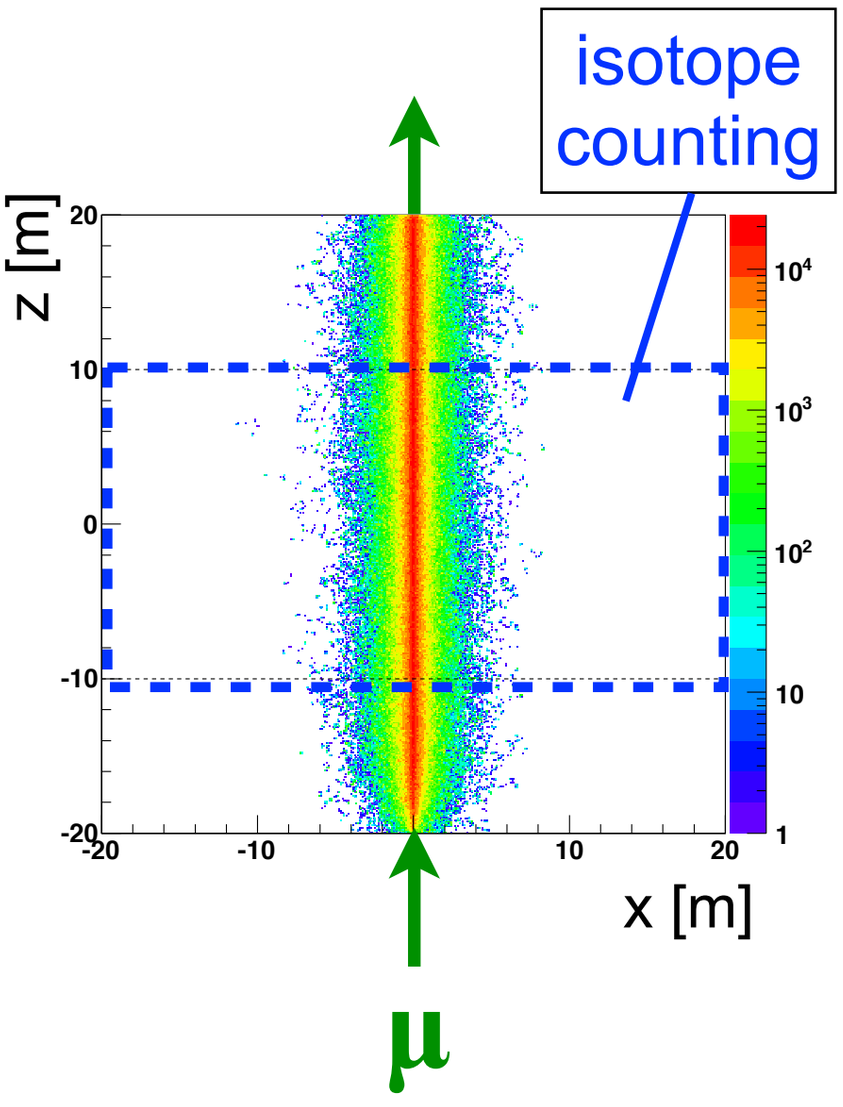
measure isotope production yield
only at central 20 m region to
reduce the boundary effect

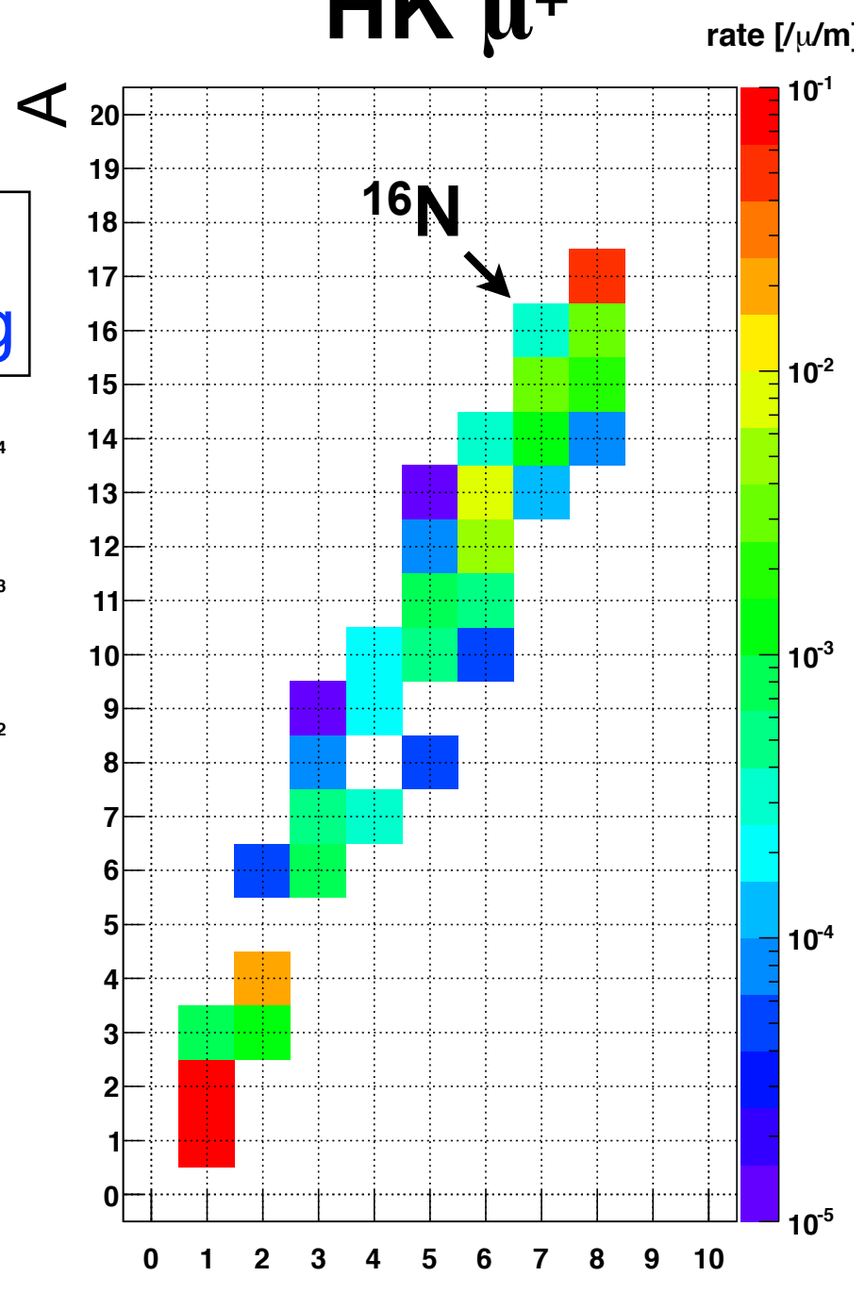


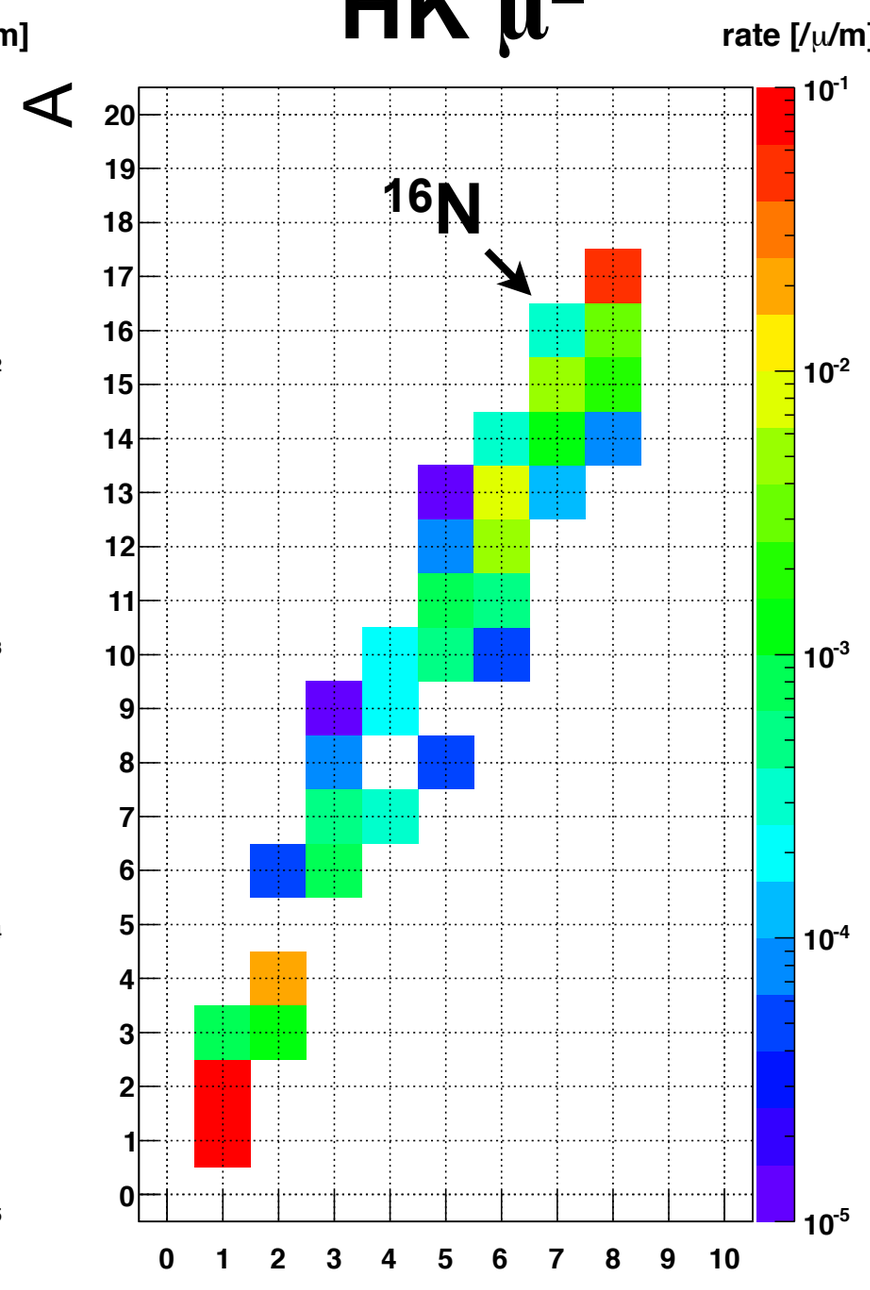
Result is used for the estimate of isotope yield ratio of HK / SK

Isotope Yield in FLUKA

isotope production
by oxygen spallation







Isotope yield (^{16}N)

(weighted average assuming $\mu^+/\mu^- \sim 1.3$)

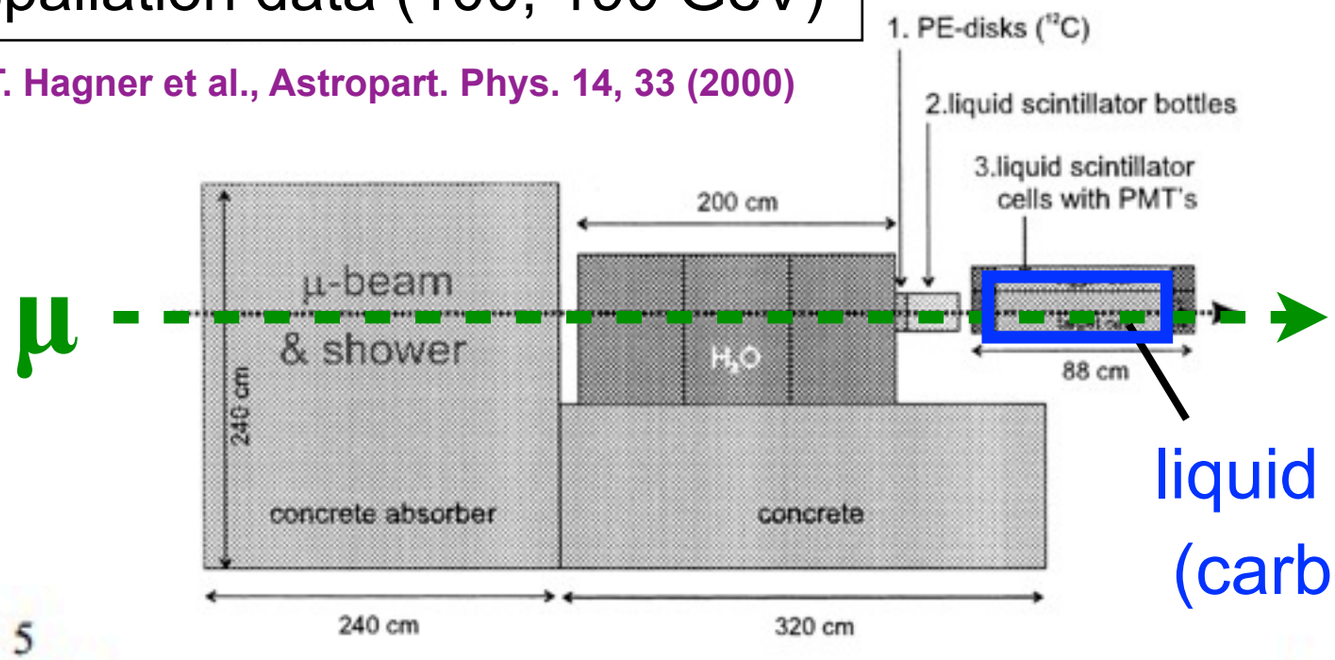
Y (HK) = 2.74×10^{-4} /μ/m

Y (SK) = 3.41×10^{-4} /μ/m

Muon Beam Experiment

spallation data (100, 190 GeV)

T. Hagner et al., Astropart. Phys. 14, 33 (2000)



liquid scintillator (carbon) target

^{11}C rate variation

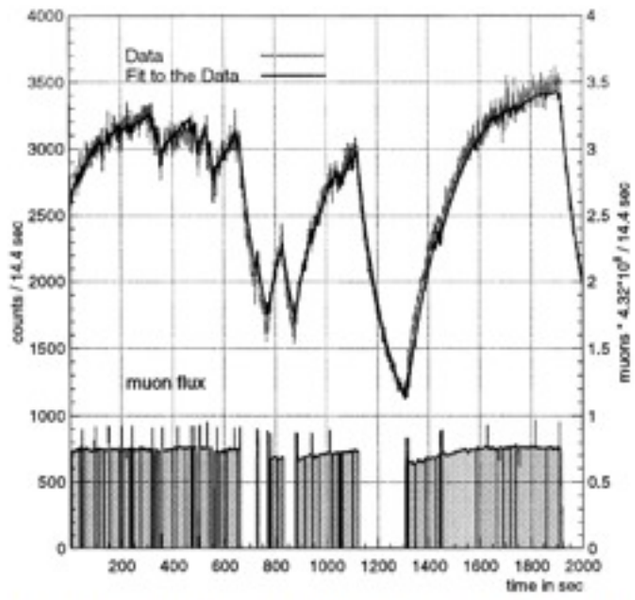


Table 5

Cross-sections σ and energy dependences α for all muon-induced radioactive isotopes which can be produced in a scintillator (^{12}C) target[a]

Isotopes	σ in μbarn for E_μ (GeV)		Energy dependence exponent α
	100	190	α
^{11}C	576 ± 45	905 ± 58	0.70 ± 0.16
^{7}Be	127 ± 13	230 ± 23	0.93 ± 0.23
^{11}Be	<1.22 (68% CL)	<2.34 (68% CL)	
^{10}C	77.4 ± 4.9	115.4 ± 14.6	0.62 ± 0.22
^{8}Li	2.93 ± 0.80	4.02 ± 1.46	0.50 ± 0.71
^{6}He	10.15 ± 1.0	16.02 ± 1.60	0.71 ± 0.22
^{8}B	4.16 ± 0.81	7.13 ± 1.46	0.84 ± 0.45
^{9}C		4.83 ± 1.51	
^{9}Li + ^{8}He		2.12 ± 0.35	

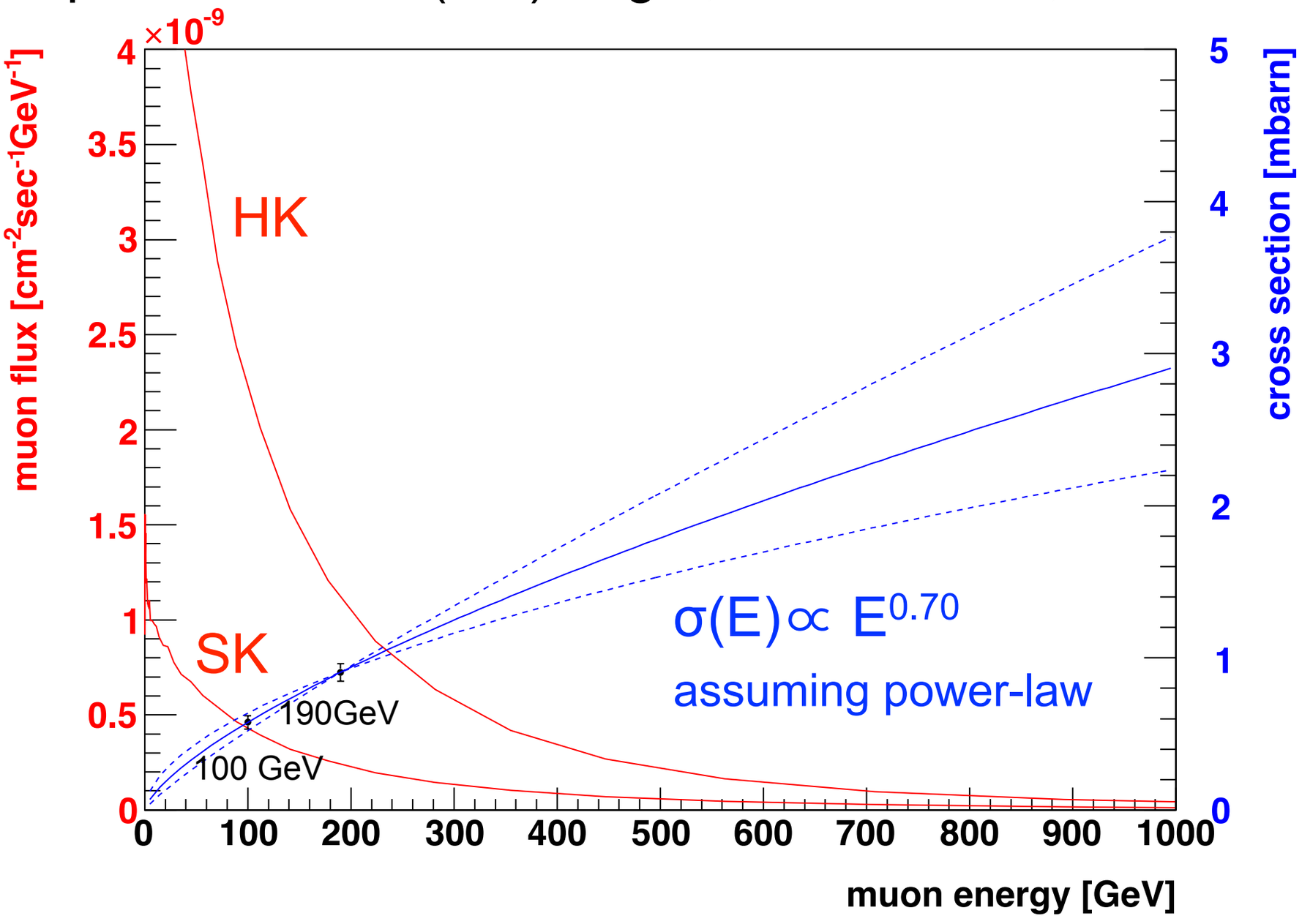
$\sigma(E) \propto E^{\alpha}$

[a] The cross-sections (given in μbarn) have been measured at two different muon beam energies, $E_\mu = 100$ GeV and $E_\mu = 190$ GeV, respectively. The weighted mean value of the exponent α is $\langle\alpha\rangle = 0.73 \pm 0.10$.

Estimation from Muon Beam Experiment

cross section from muon beam experiment + MUSIC MC

liquid scintillator (^{12}C) target, E = 100 GeV, 190 GeV



Ratio of ^{11}C production rate (HK / SK) = 4.14 ± 0.84

~20% from muon MC

~4% from c.s.

Production Yield per Muon

Ratio of isotope yield (HK / SK) has ~10% spread in Data and MC

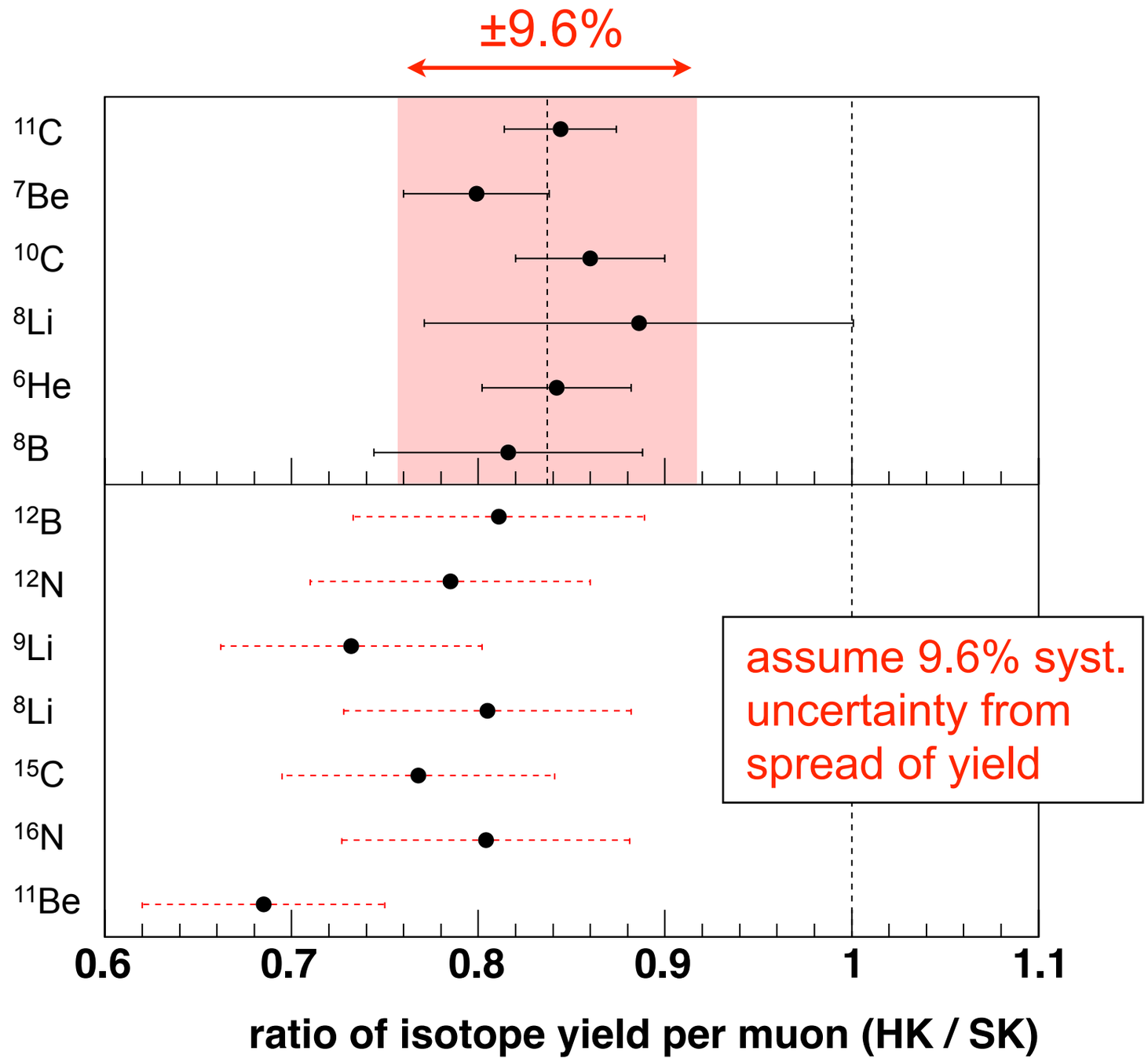
Muon beam experiment

liquid scintillator target

Hagner et al., Astro. Phys. 14, 33 (2000)

FLUKA MC simulation

water target



Ratio of isotope yield (^{16}N) (HK / SK) = **0.80 ± 0.08**

Estimation of Isotope Yield at HK

Ratio of muon flux (HK / SK) = **4.90 ± 0.98**

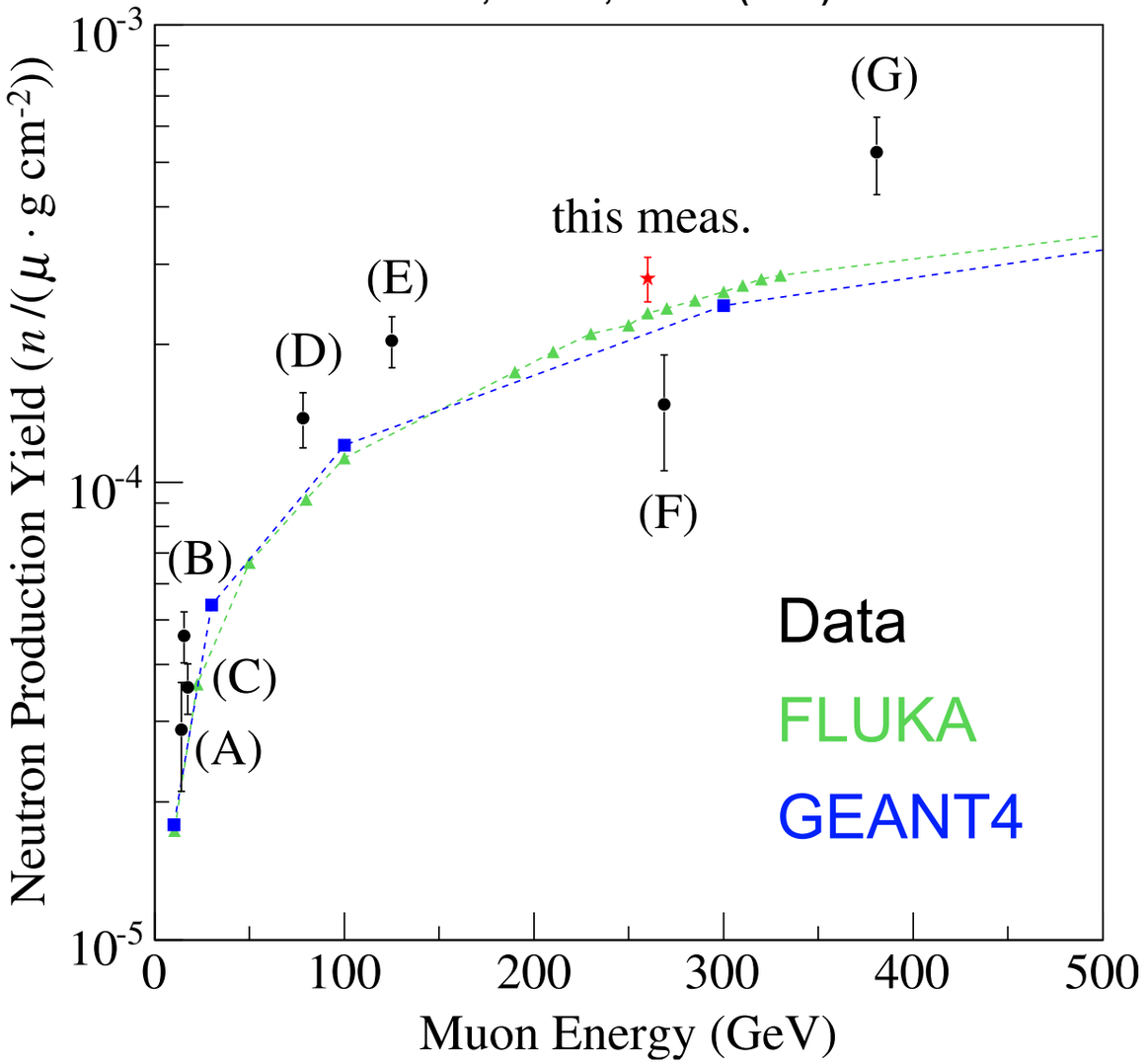
	Isotope yield by FLUKA (/μ/m)		Ratio of yield (HK / SK)	Ratio of rate (HK / SK)
	HK	SK		
^{12}B	8.05×10^{-5}	9.93×10^{-5}	0.811 ± 0.078	**3.98 ± 0.88**
^{12}N	8.70×10^{-6}	1.11×10^{-5}	0.785 ± 0.075	**3.84 ± 0.85**
^{9}Li	1.23×10^{-5}	1.68×10^{-5}	0.732 ± 0.070	**3.59 ± 0.80**
^{8}Li	8.67×10^{-5}	1.08×10^{-4}	0.805 ± 0.077	**3.95 ± 0.87**
^{15}C	5.12×10^{-6}	6.68×10^{-6}	0.768 ± 0.073	**3.76 ± 0.83**
^{16}N	2.74×10^{-4}	3.41×10^{-4}	0.804 ± 0.077	**3.94 ± 0.87**
^{11}Be	5.32×10^{-6}	7.76×10^{-6}	0.685 ± 0.065	**3.36 ± 0.74**

Expected rate of spallation background has uncertainty of ~20%

Prospect in Gadolinium Option

neutron yield in liquid scintillator

S. Abe et a., PRC81, 025807 (2010)



MC is almost consistent with Data

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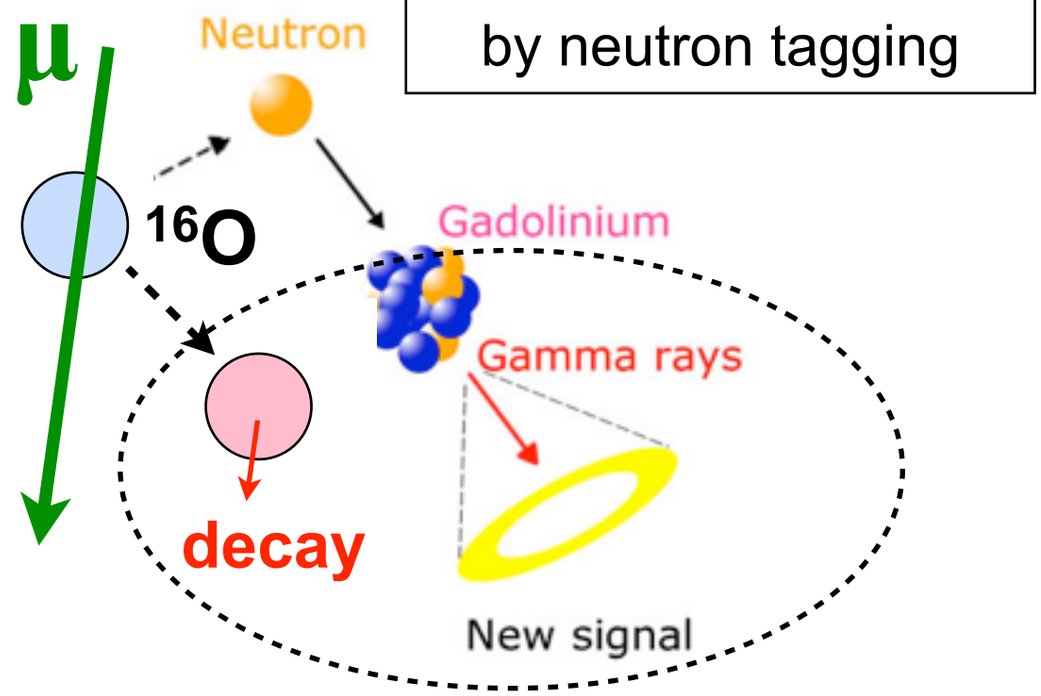
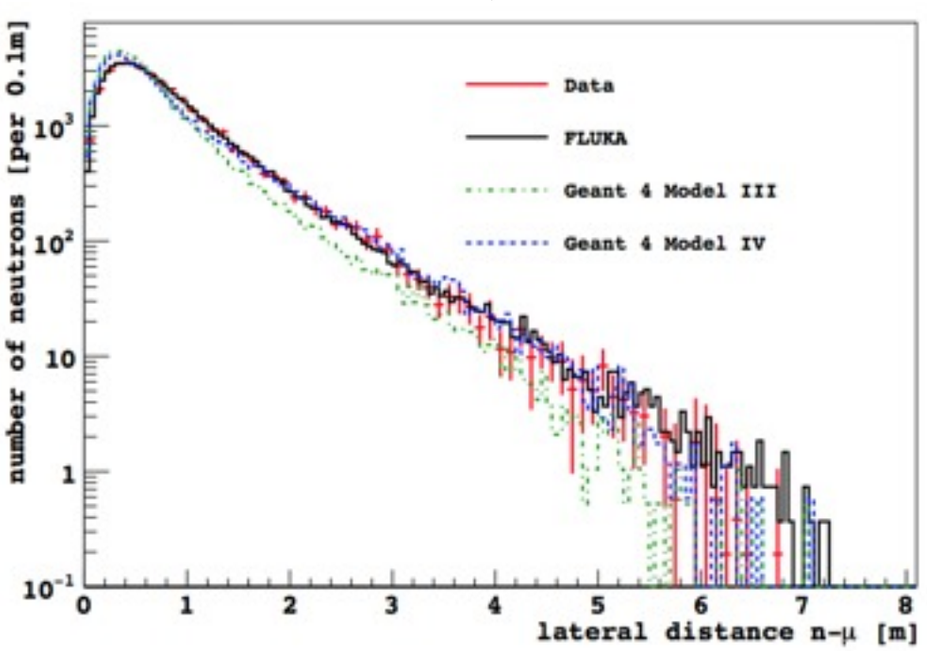
study BG reduction and signal efficiency in ^{16}O using MC

spallation BG rejection by neutron tagging



ΔL distribution in liquid scintillator

G. Bellini et a., arXiv:1304.7381



Summary

- Expected rate of spallation background at HK will be increased by factor **~4 ± 1** (previous ~7) over SK including updated HK position and elevation data.

Ratio of total muon flux (HK / SK) = **4.90 ± 0.98***

Ratio of isotope yield (^{16}N) (HK / SK) = **0.80 ± 0.08**

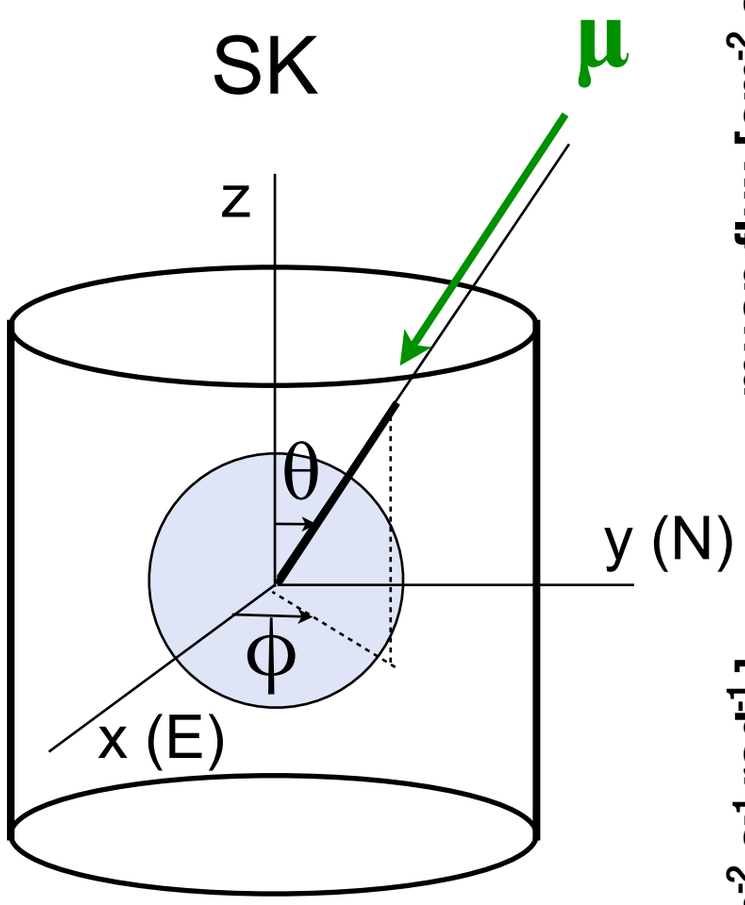
***flux at HK basing point**

- Prediction uncertainty is dominated by the muon flux which may be determined by in-situ measurement (hodoscope) at existing drift.

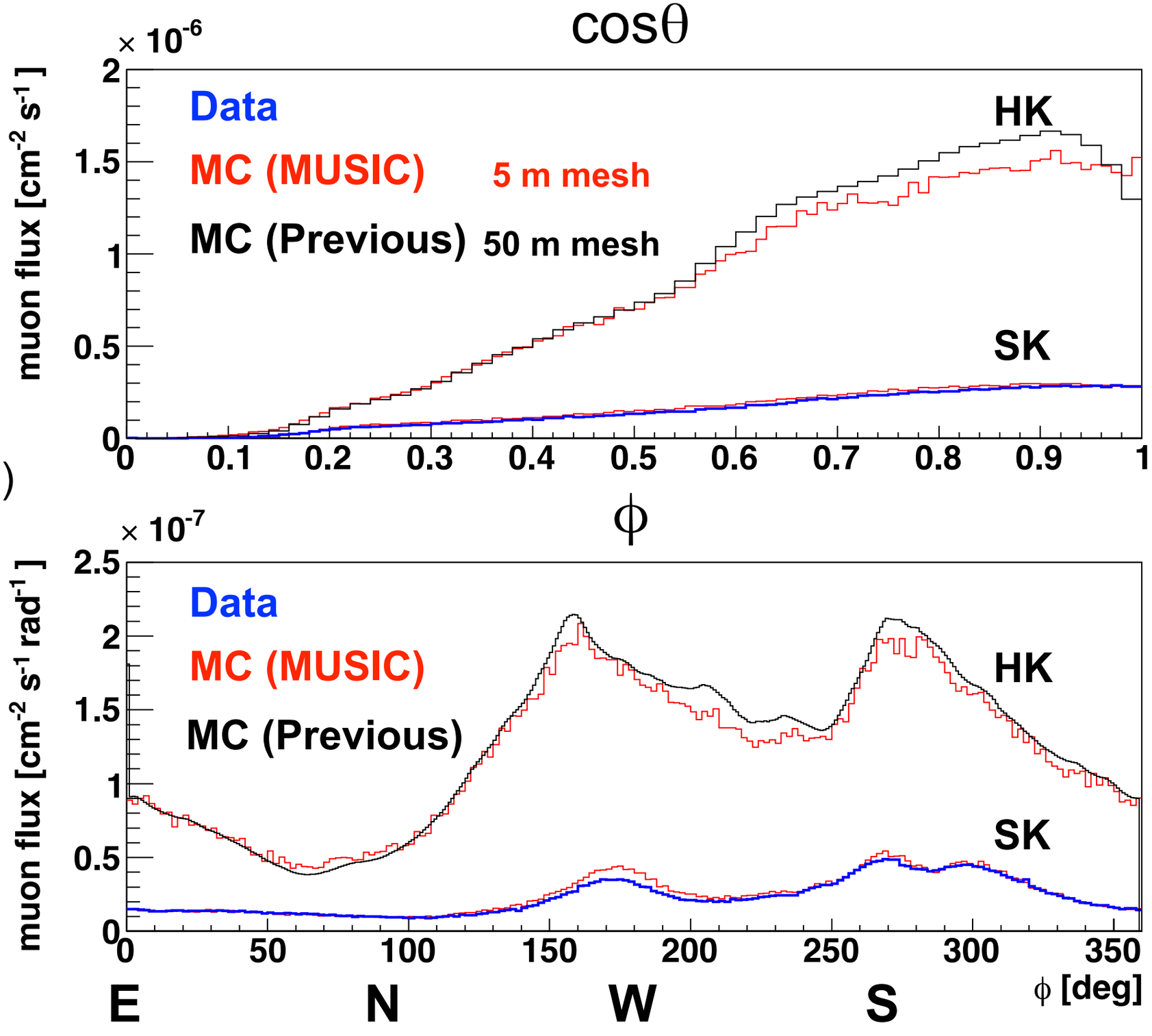
- Neutron production MC will be useful to evaluate the reduction efficiency for spallation BG (Gd option).

Backup

Comparison of Muon Flux at HK / SK

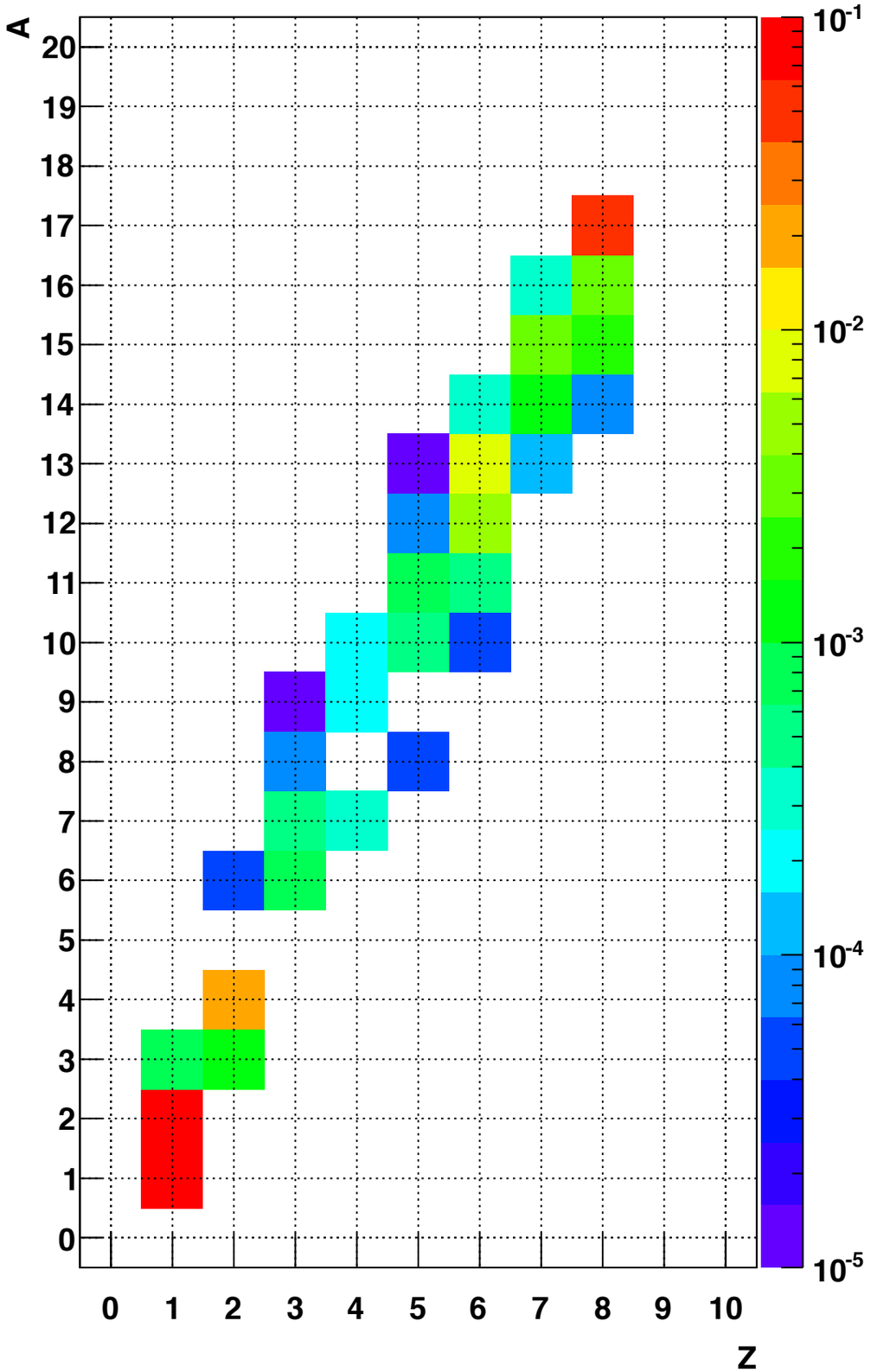


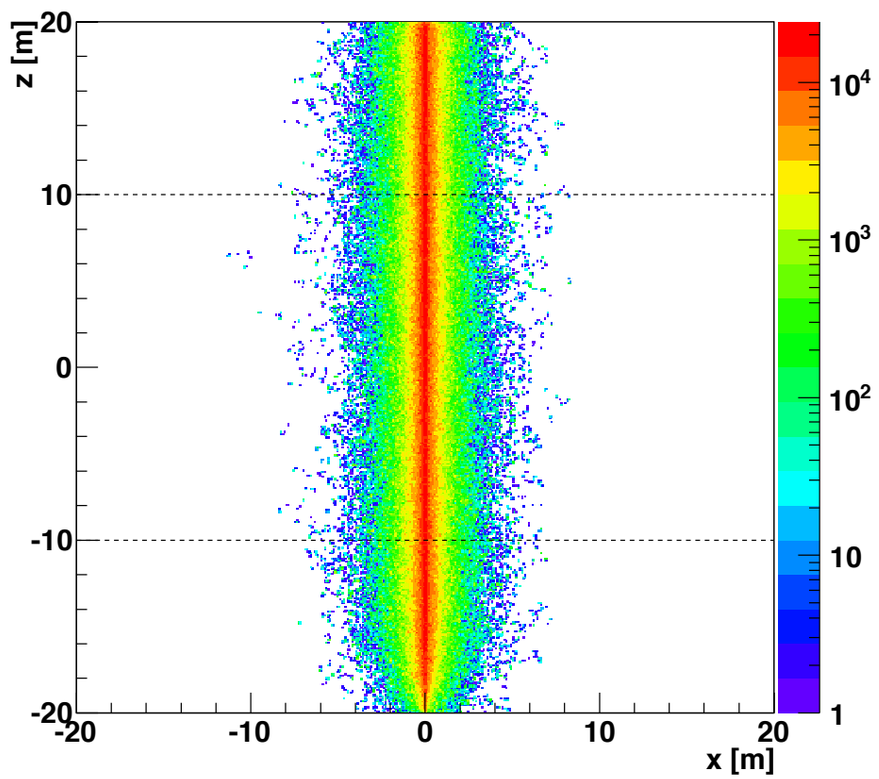
muon flux measurement
with 12 day data
in spherical volume
(R = 10 m)

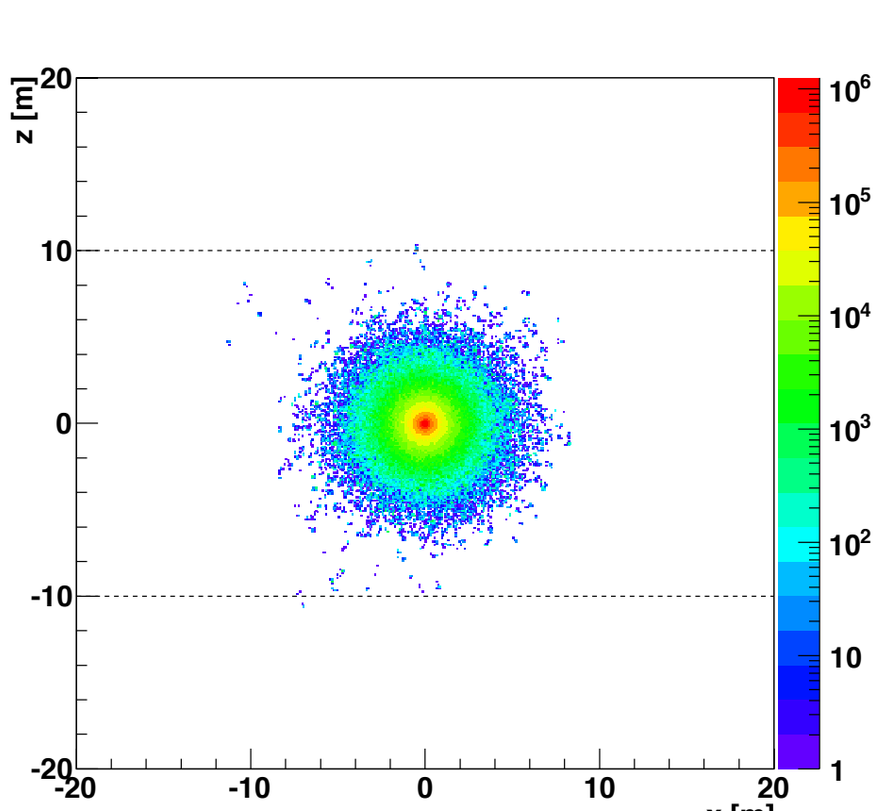


Ratio of total muon flux (HK / SK) = **4.90 ± 0.98**

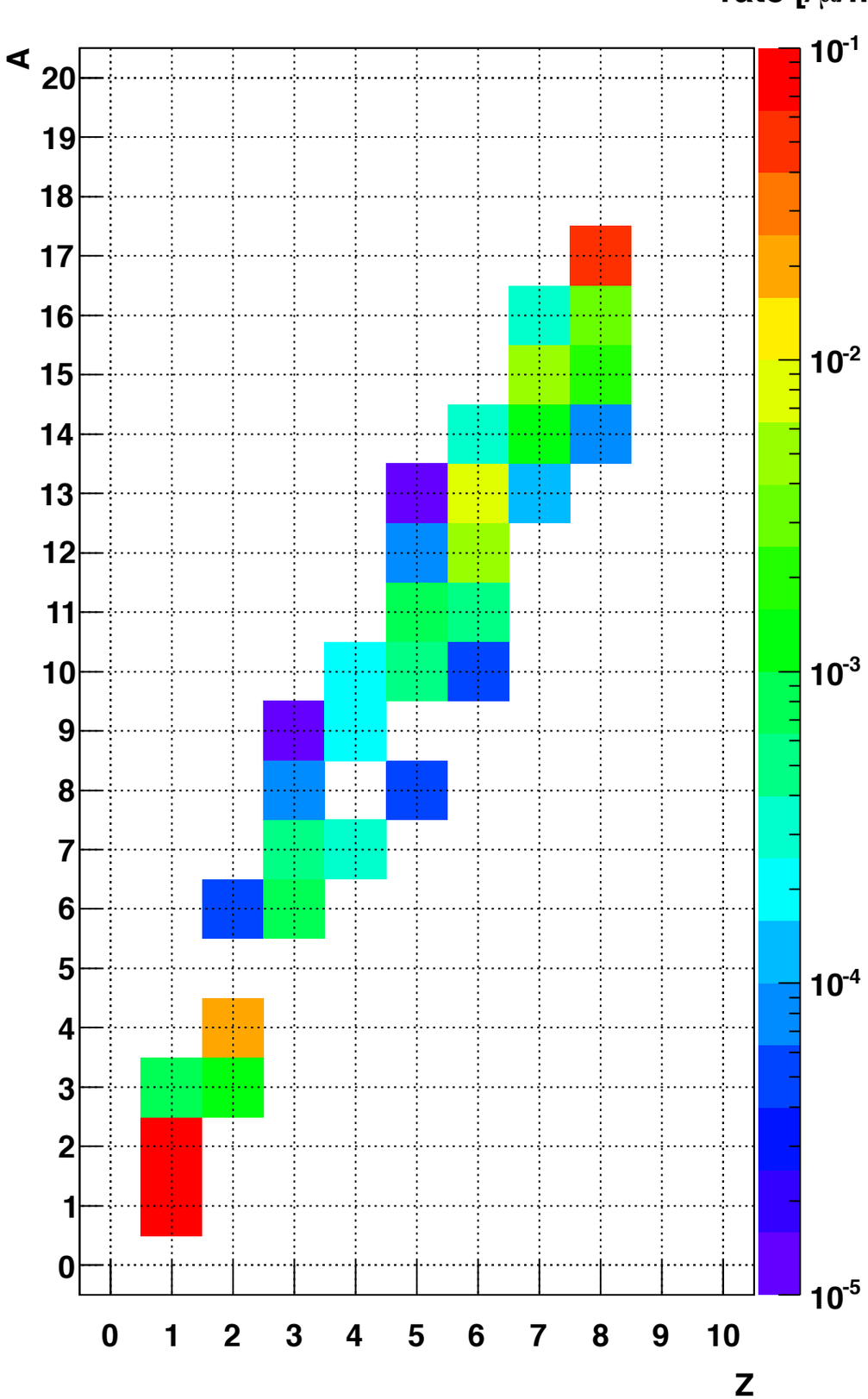
Fluka: HK μ^+

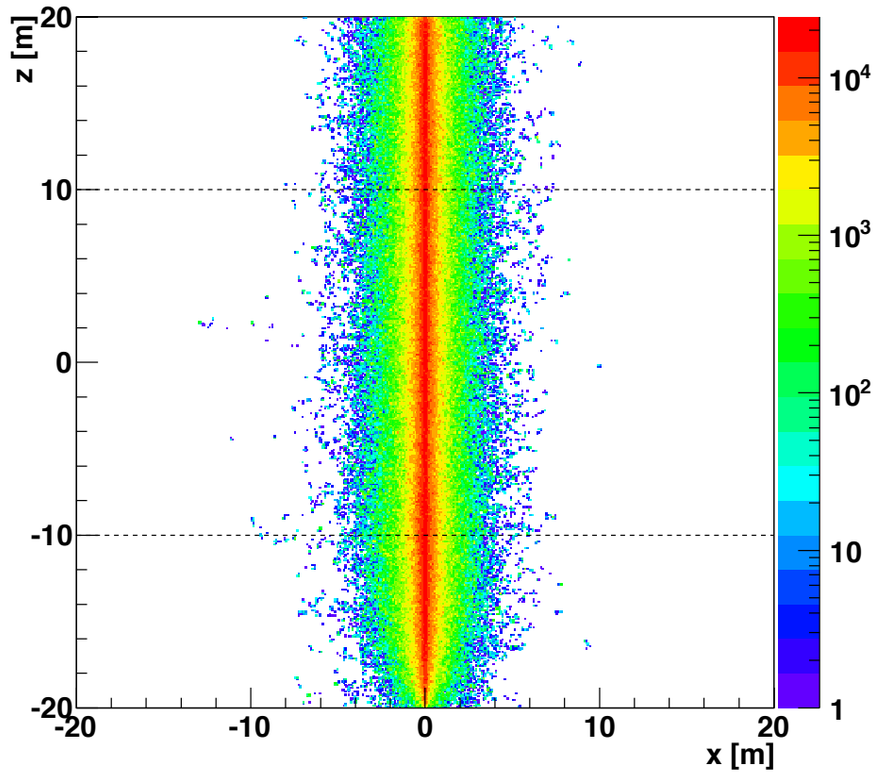

rate [/μ/m]
A
Z
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

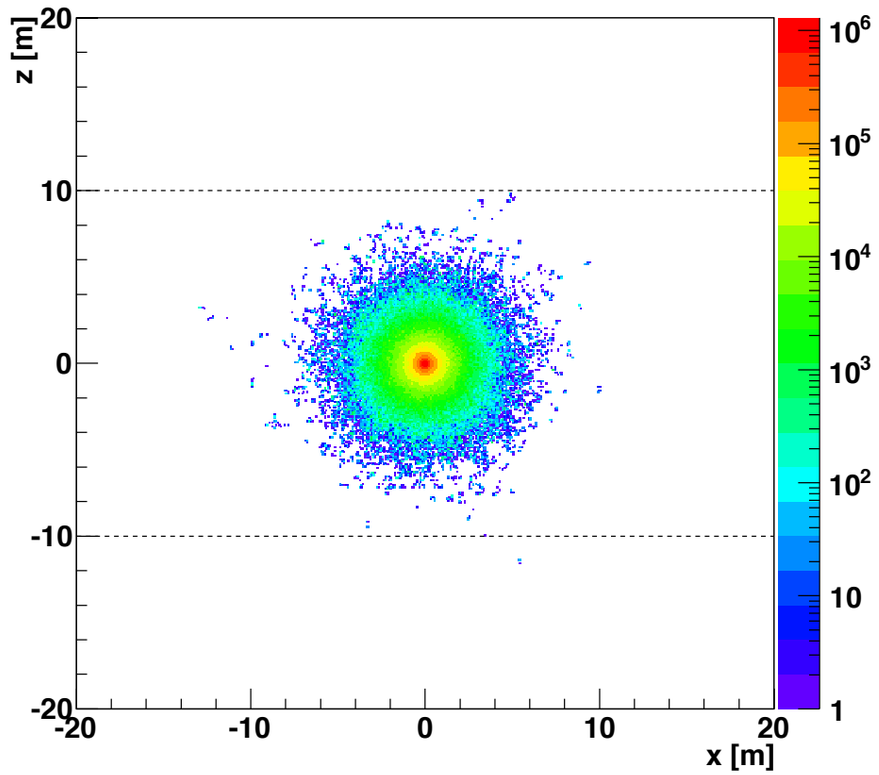

z [m]
x [m]
-20 -10 0 10 20
10^4
10^3
10^2
10
1


z [m]
x [m]
-20 -10 0 10 20
10^6
10^5
10^4
10^3
10^2
10
1

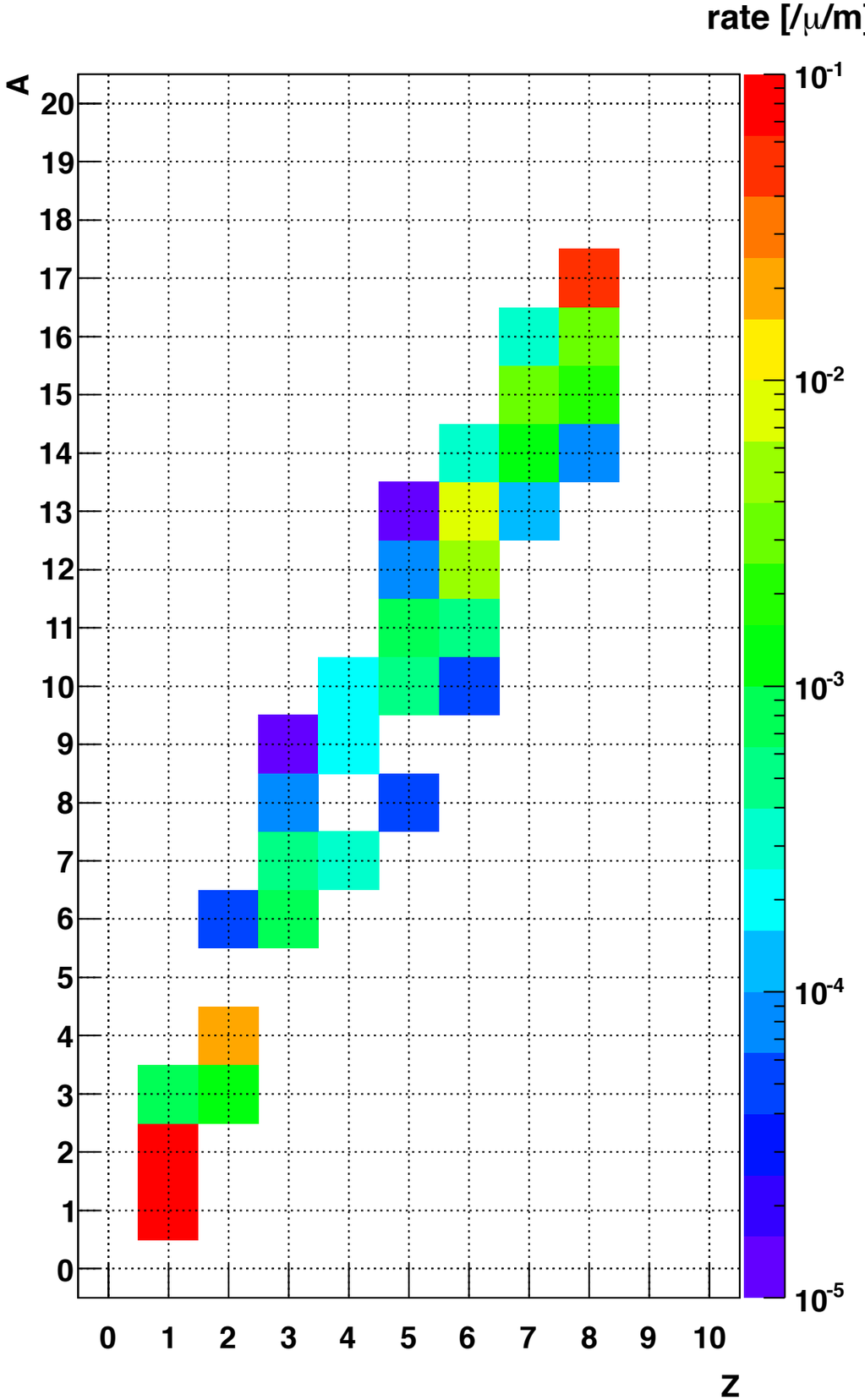
Fluka: HK μ^-

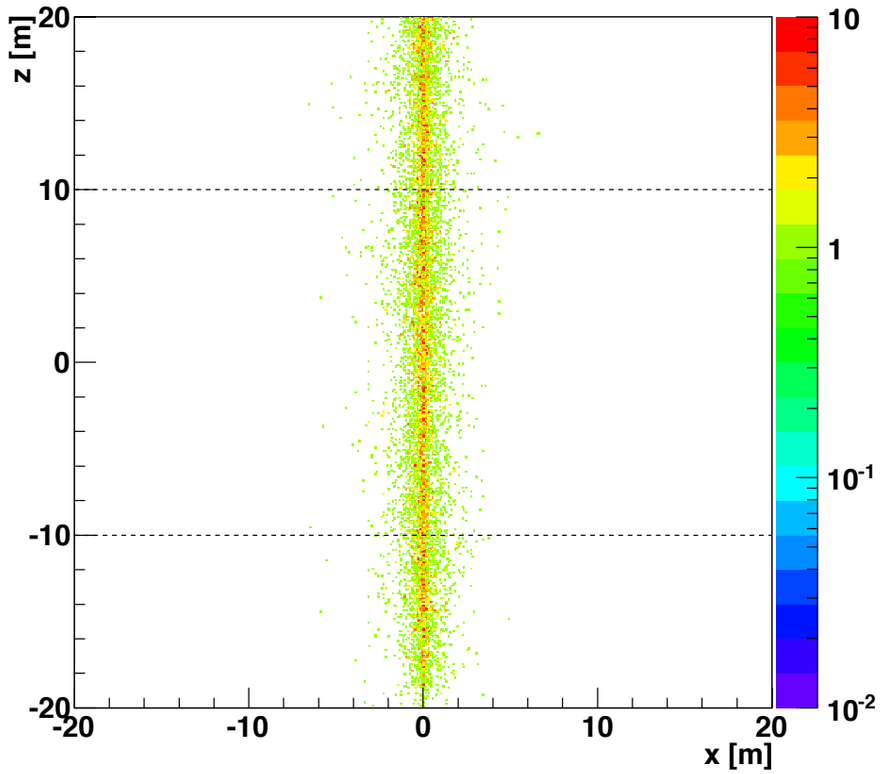

rate [/μ/m]
A
Z
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
10^-1
10^-2
10^-3
10^-4
10^-5

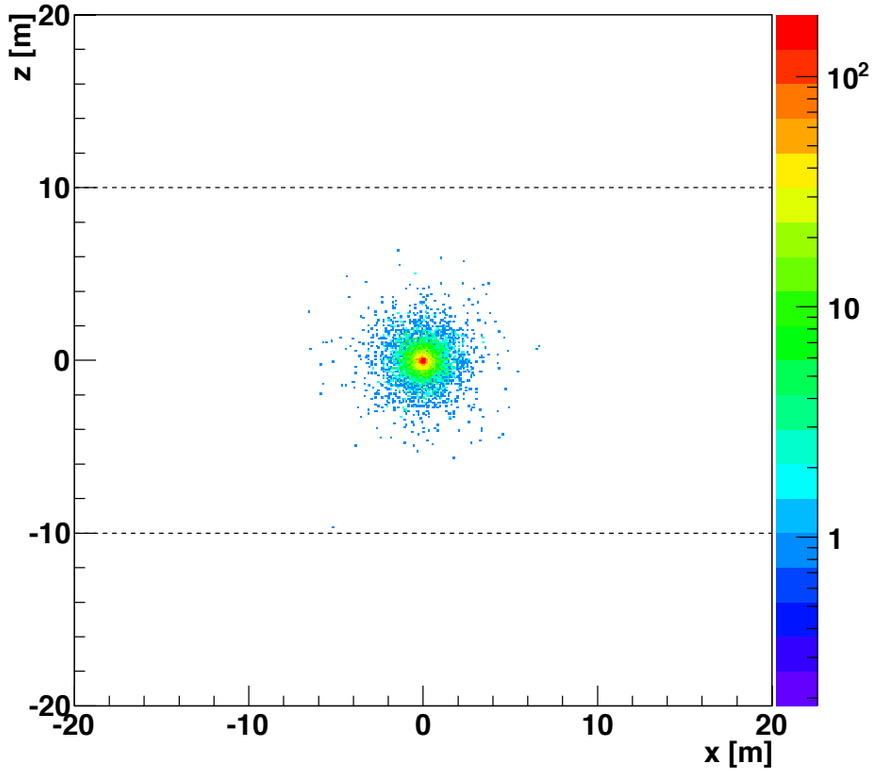

z [m]
x [m]
-20 -10 0 10 20
10^4
10^3
10^2
10
1


z [m]
x [m]
-20 -10 0 10 20
10^6
10^5
10^4
10^3
10^2
10
1

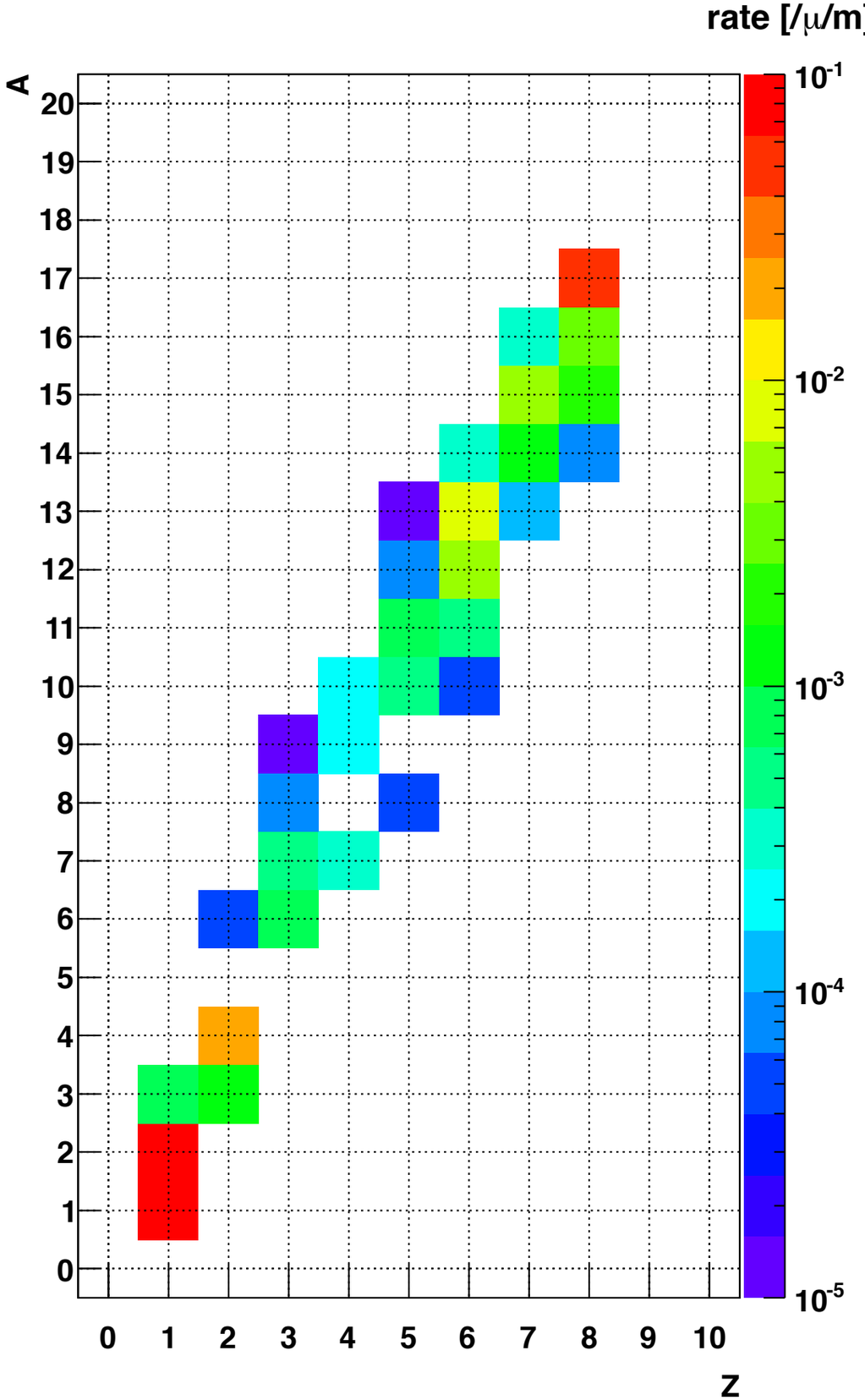
Fluka: HK μ^+ (^{16}N)

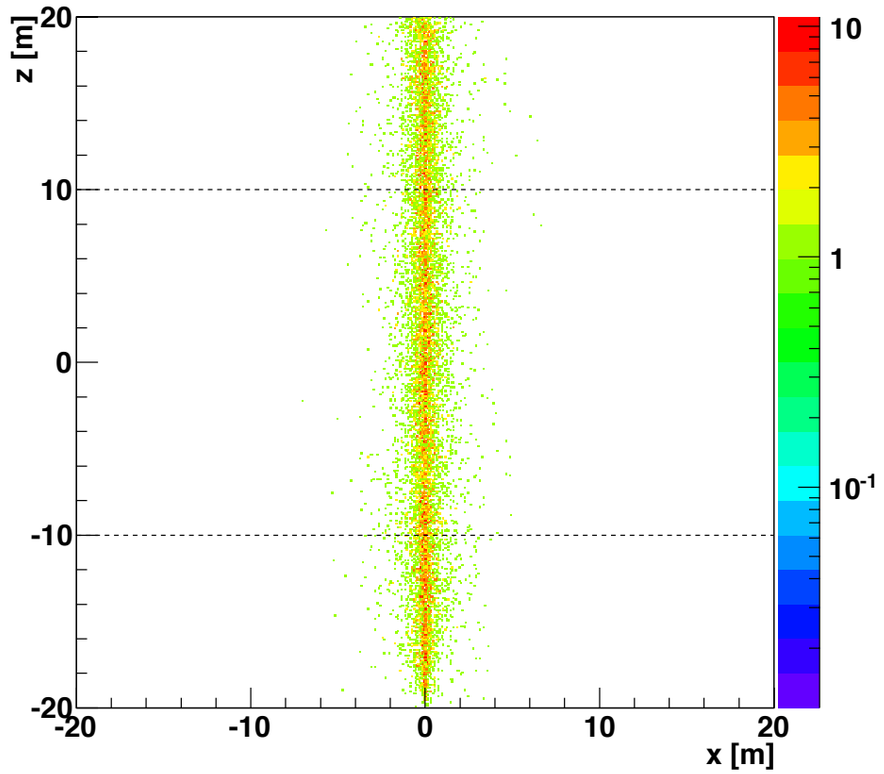


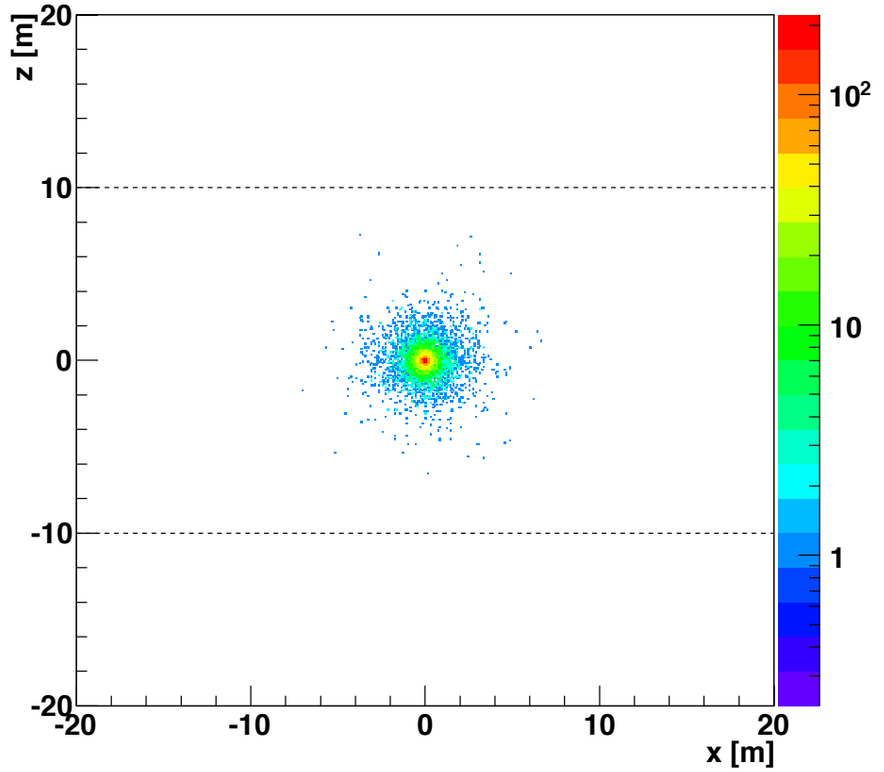




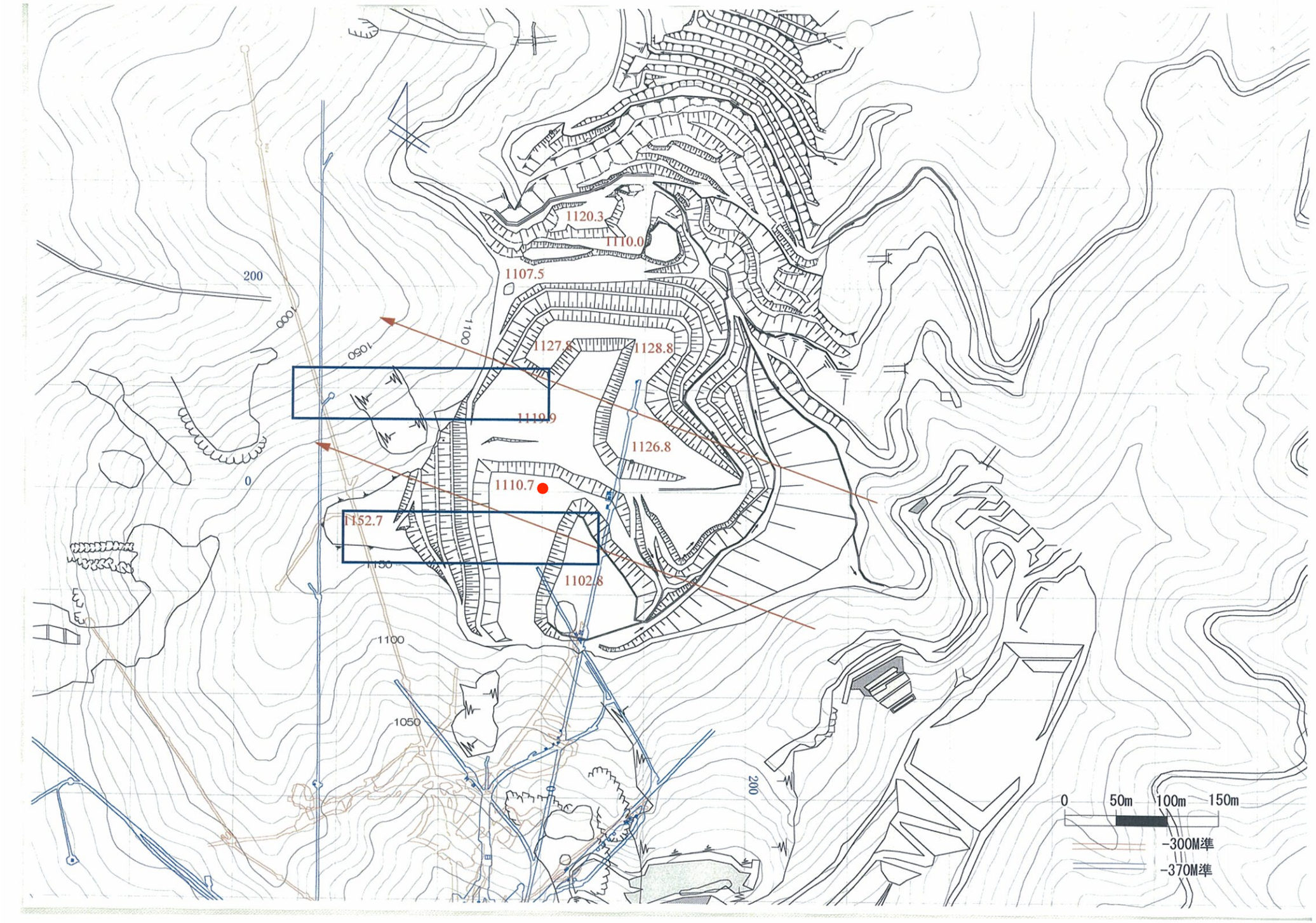
Fluka: HK μ^- (^{16}N)







Map provided by mine company (basing point, HK)



■住所で移動

移動

■緯度・経度（60進）で移動

緯度 36 度 21 分 19.44 秒

経度 137 度 18 分 48.72 秒 移動

■緯度・経度(10進)で移動

緯度 36.3554

経度 137.313535 移動

標高取得 1131.0000 m

単位変換 メートル[m]

クリア コントロール非表示 ヘルプ

インフォメーション

住所

GoogleMaps V3版はこちら

携帯版はこちら
（docomoで動作確認）

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