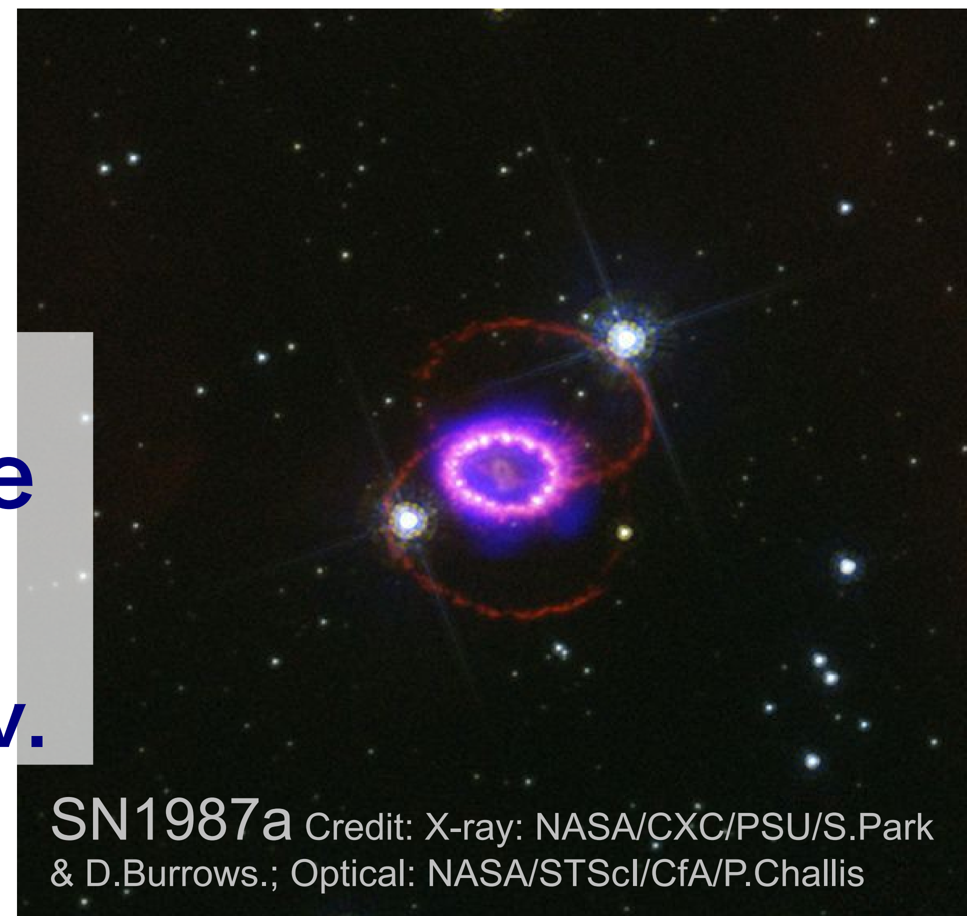
Supernova Relic Neutrino Search with Hyper Kamiokande

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



2nd Open Meeting for Hyper Kamokande

14th January 2013.
At Kavli IPMU, Tokyo Univ.

Motivation of this analysis

- **Motivation**

To study the effect of the location (depth) on SRN search with HK.

(Muon flux ×1, ×3, ×5, ×7 and ×10 cases)

- **Contents**

1. SRN search with Hyper Kamiokande.
2. SRN search with HK + Gd.

Current Status of SRN Search with SK

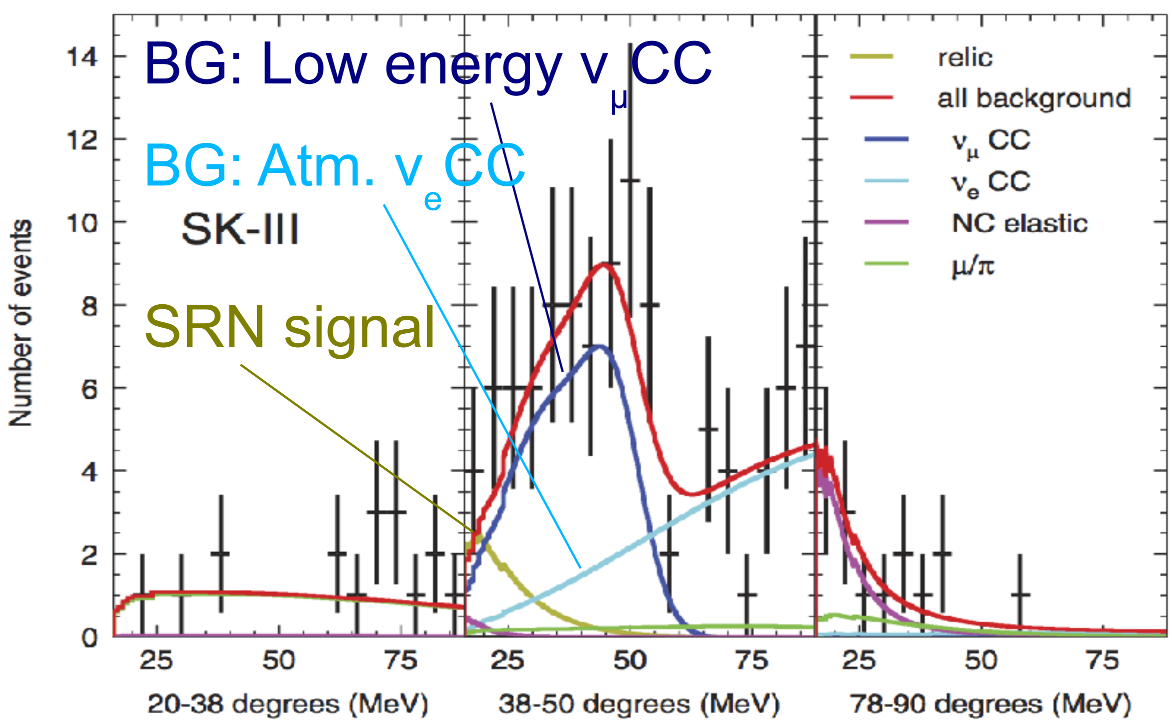
Supernova Relic Neutrino is diffused neutrino background from supernovae > ~Mpc.

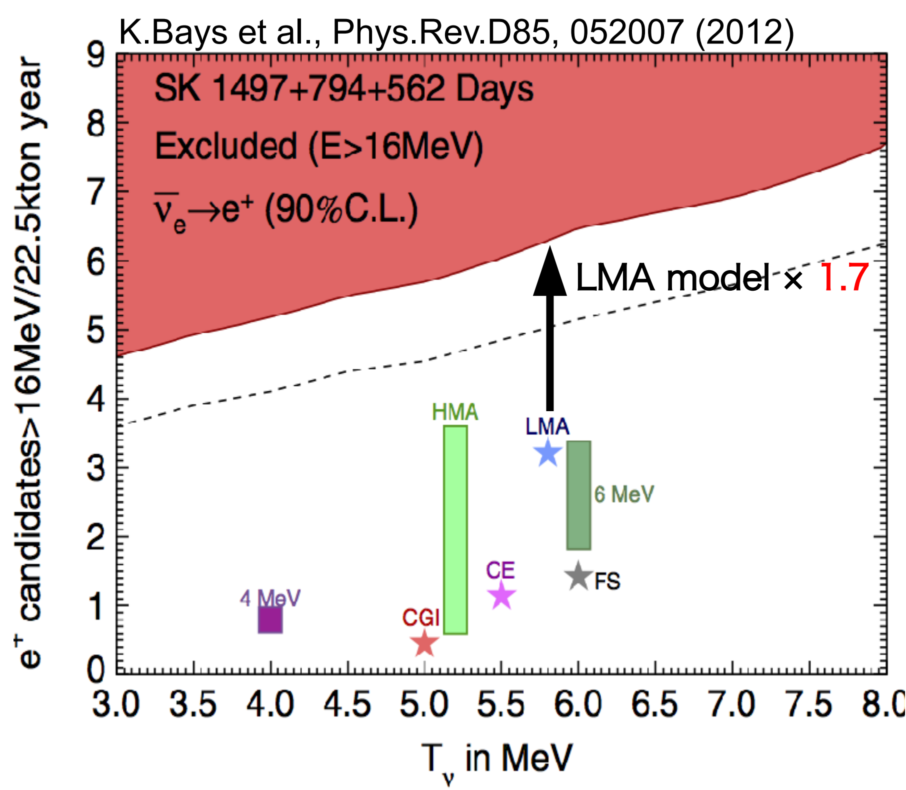
Recent SRN search was done with single positron tag analysis.

(K.Bays et al., Phys.Rev.D85, 052007 (2012))

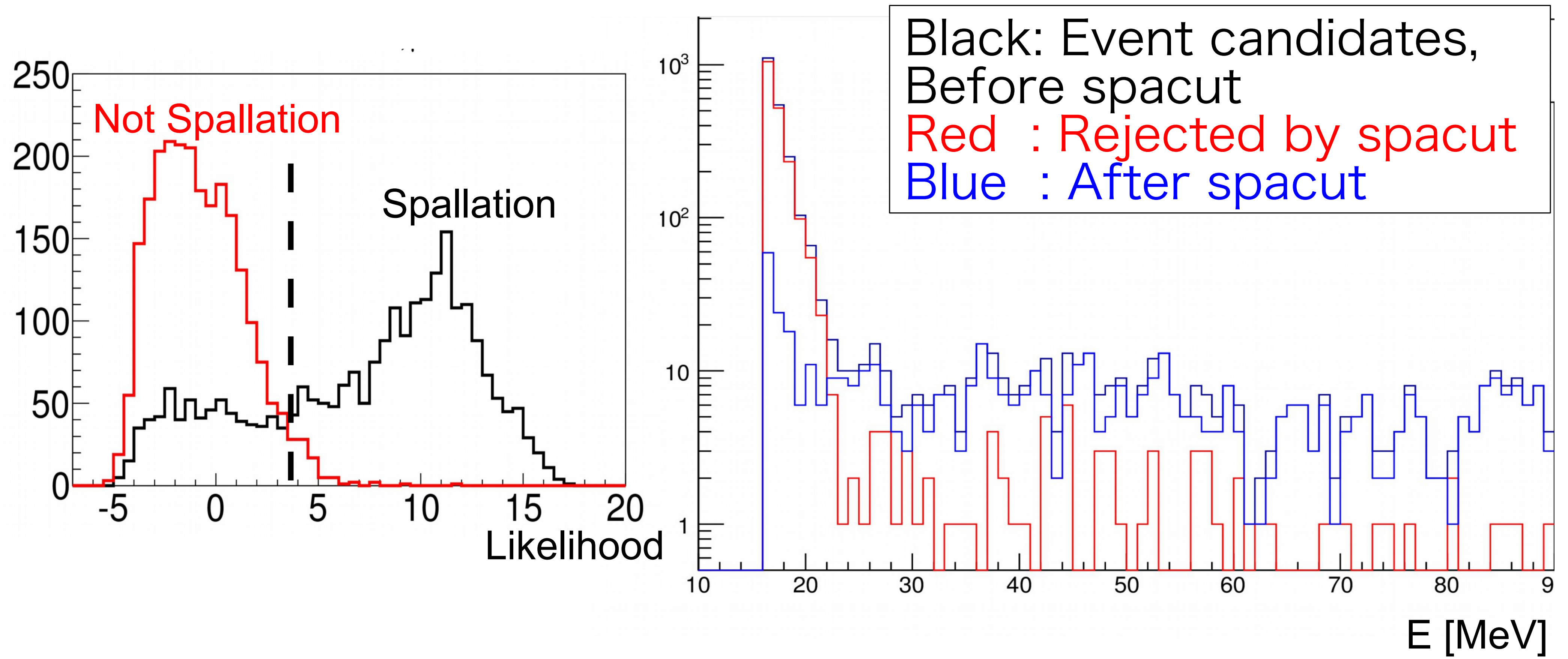
- SRN Flux < 1.7× LMA Flux (90%CL)

A new spallation likelihood cut (**Relic spacut**) was applied.





Relic spacut

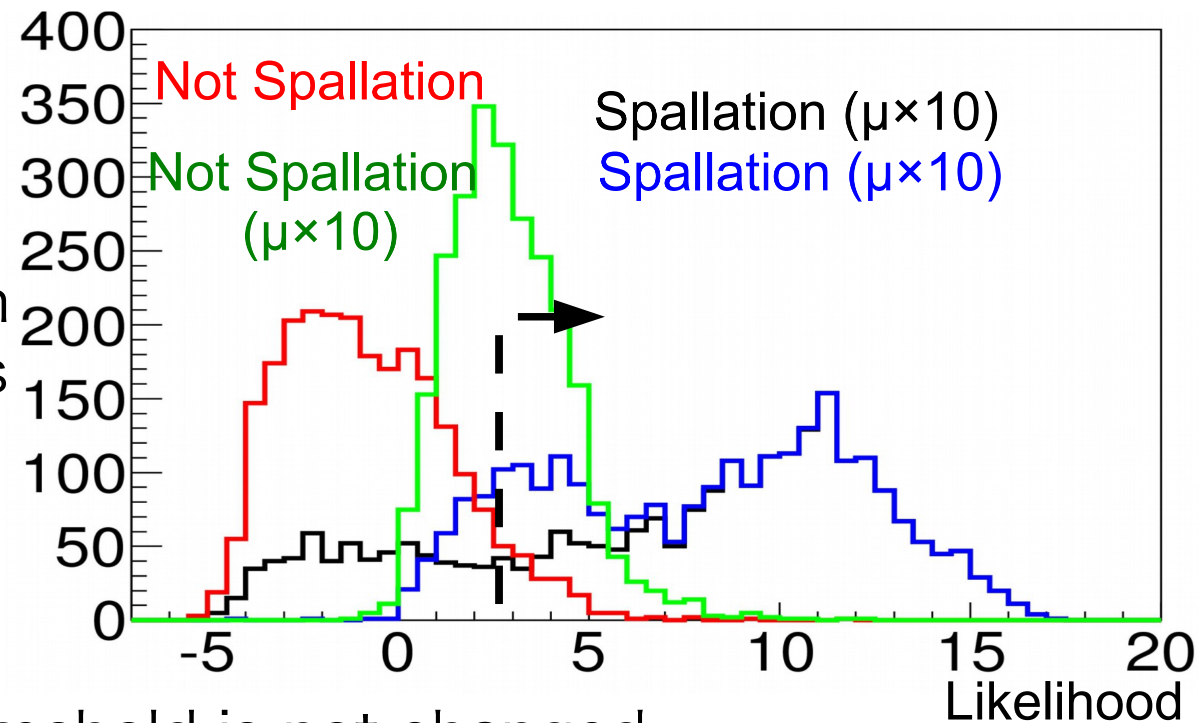


Negligible spallation events are left after relic spacut.
Remaining backgrounds are from neutrinos.

- Solar neutrinos (will be reduced by solar directional cut)
- Atmospheric NC, ν_e and ν_μ CC

Effect of more muons

- The more cosmic muons result in the worse separation between the spallation events and the others.



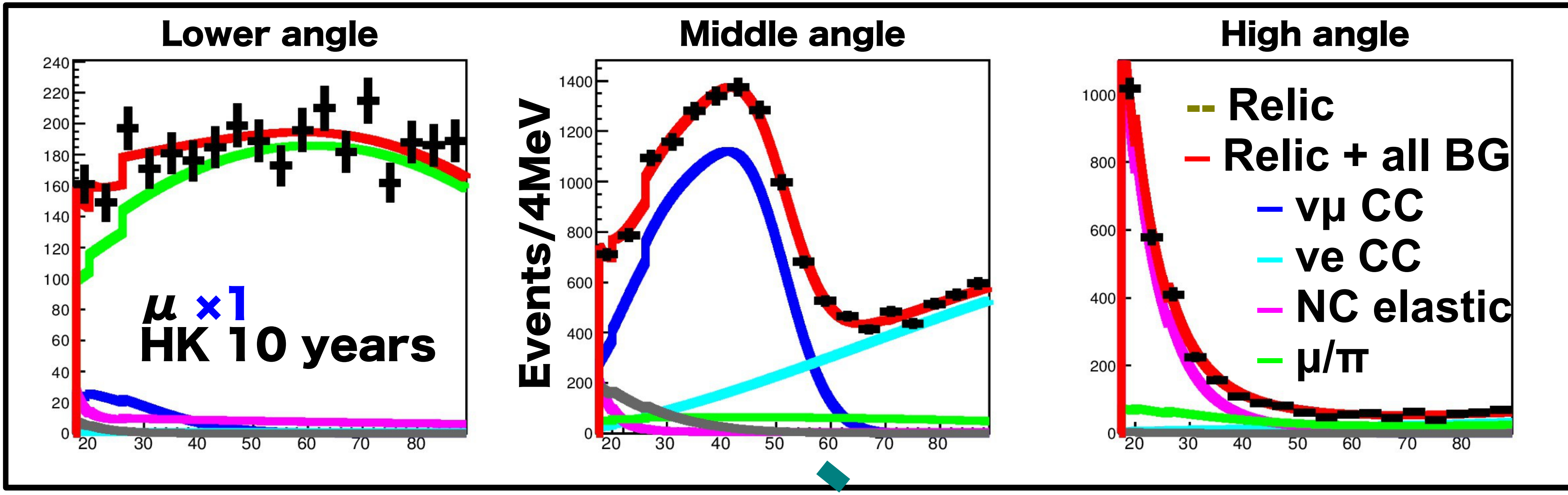
- For SRN study, Likelihood threshold is not changed.
- It retains same spallation reduction efficiency.

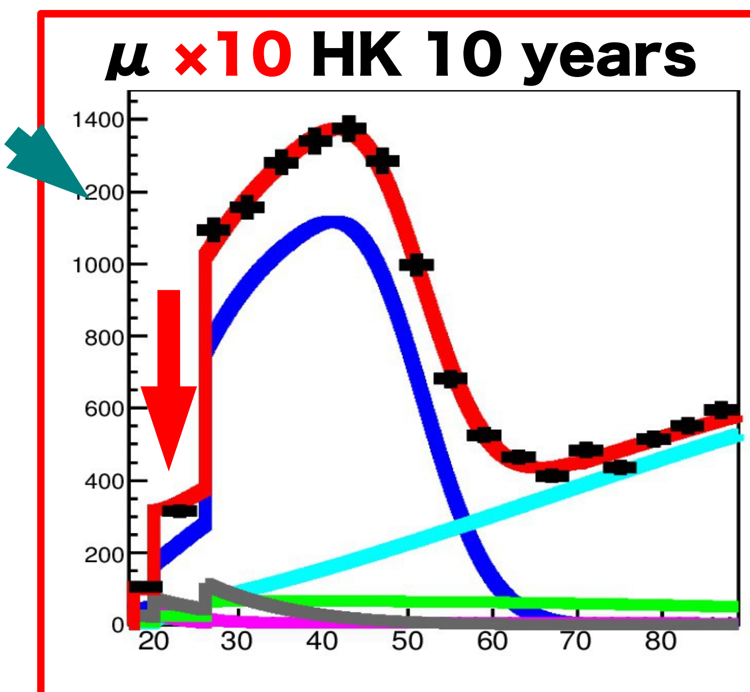
  = Negligible spallation events after spacut.
- But **it reduces the signal efficiency**.

Signal Efficiency	Cosmic μ ×1	×2	×3	×5	×7	×10
17.5-20MeV	81%	65%	52%	33%	21%	11%
20-26MeV	90%	81%	74%	59%	46%	35%

More cosmic muons, worse signal efficiency

Event Sample and Spectrum Fit



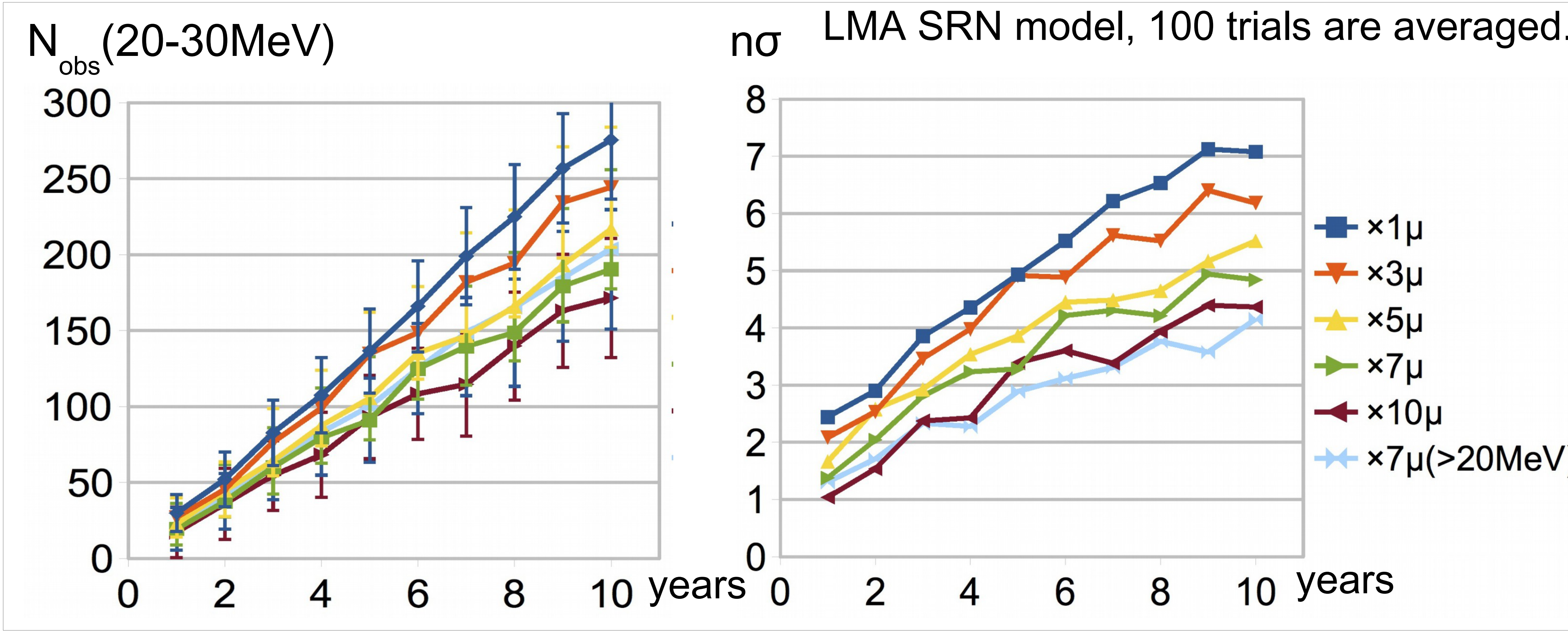


1. Event samples are made from SK-II best fit **BG** spectrum and expected **SRN** spectrum (LMA model, Ando et al. 2003) and randomize by Poisson distribution.

2. Signal efficiency is considered.

3. The event samples are fitted with these spectra, using MINUIT2 (ROOT).

of SRN Events and Significance

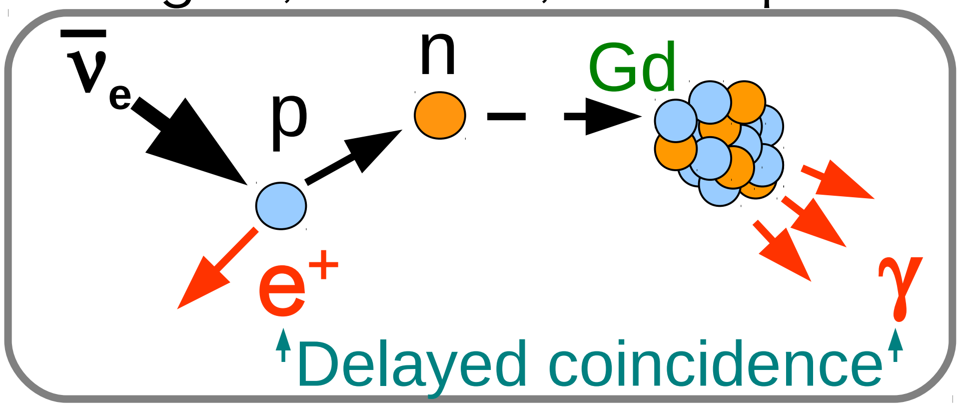


The numbers of observed SRN events (20 - 30 MeV) and the non-zero significances ($n = N_{obs}/[\text{fit error } \sigma]$) are shown.

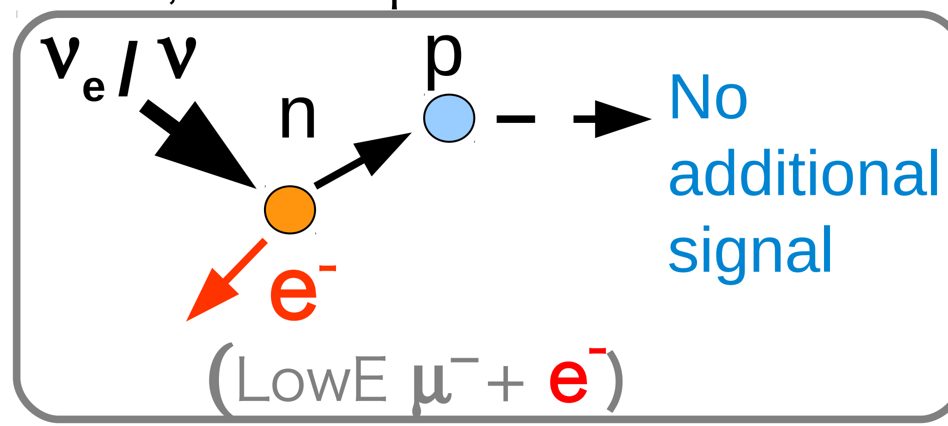
- In ×1μ case (same rate as SK), the significance will be ~5σ after 5 years, 7σ after 10 years.
- In ×7μ case, it stays at about 5σ after 10 years.
- The worst case, if only >20 MeV is available for ×7μ, it stays at 4σ.
- In most pessimistic model, Cosmic Gas Infall, the nσ will be ~1/6.

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.).

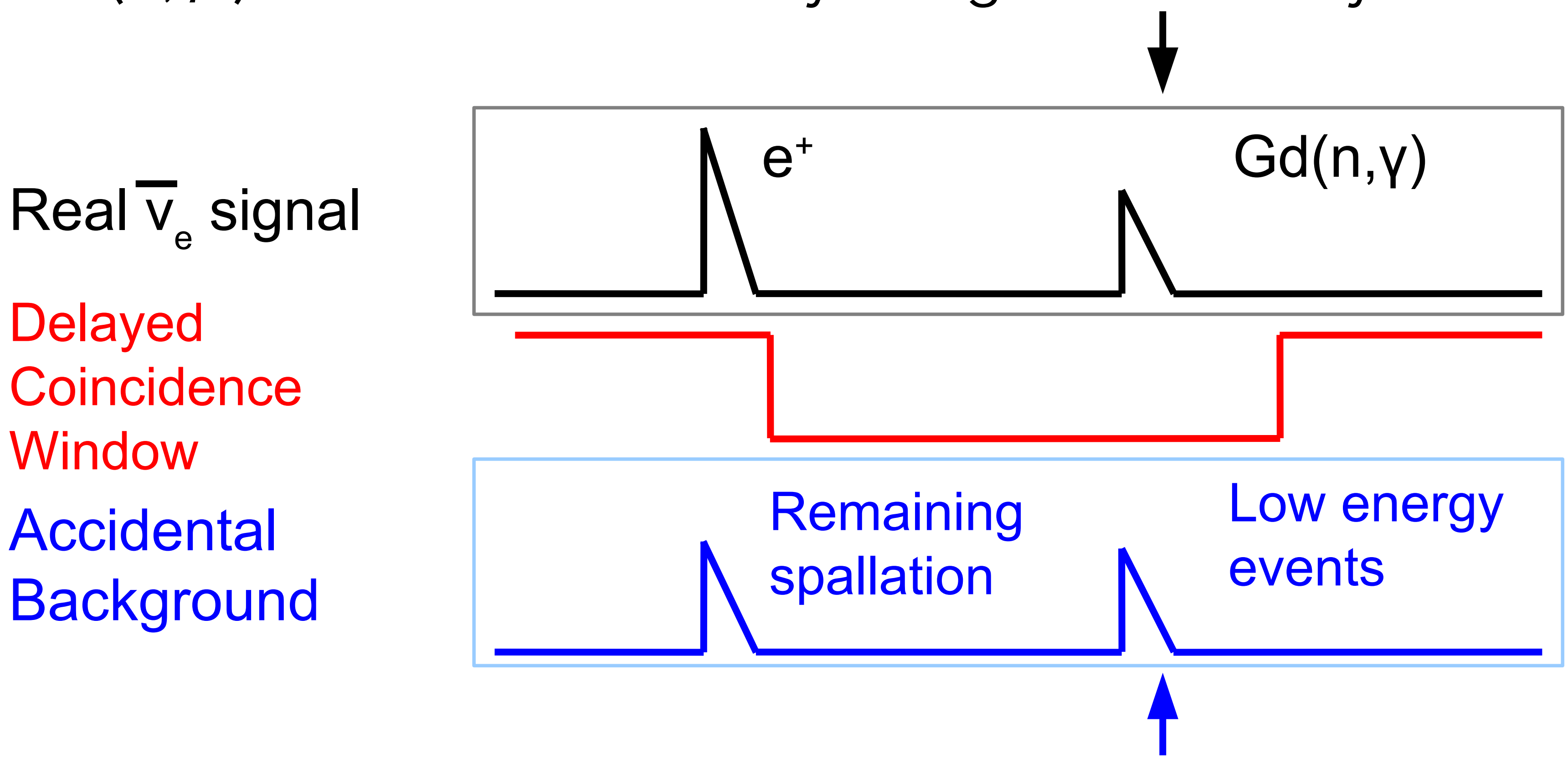
No study for Hyper-K, photo coverage 20% and more μ.

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.

Gd(n, γ) detection efficiency = Signal efficiency



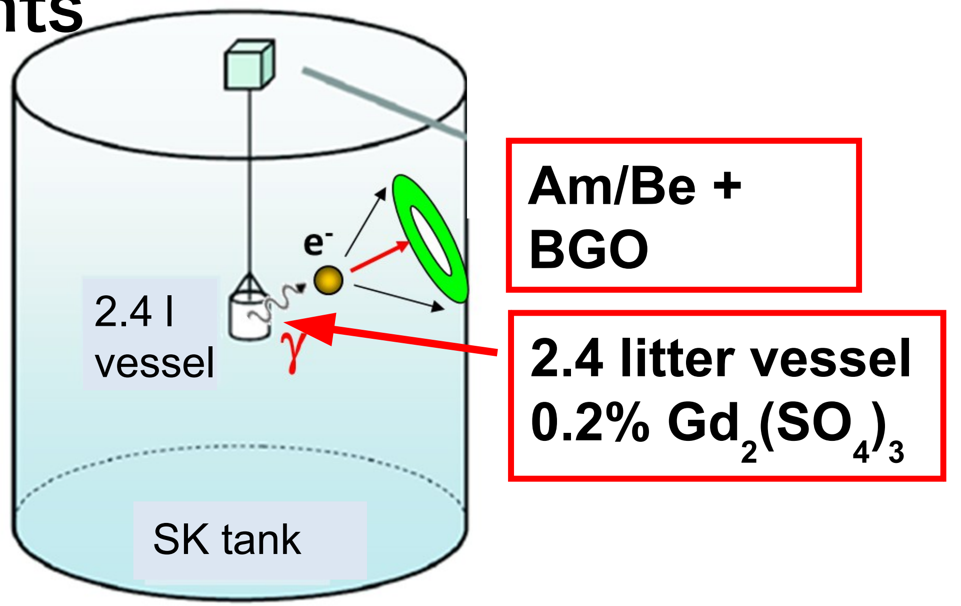
Accidental coincidence = max. BG reduction efficiency

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

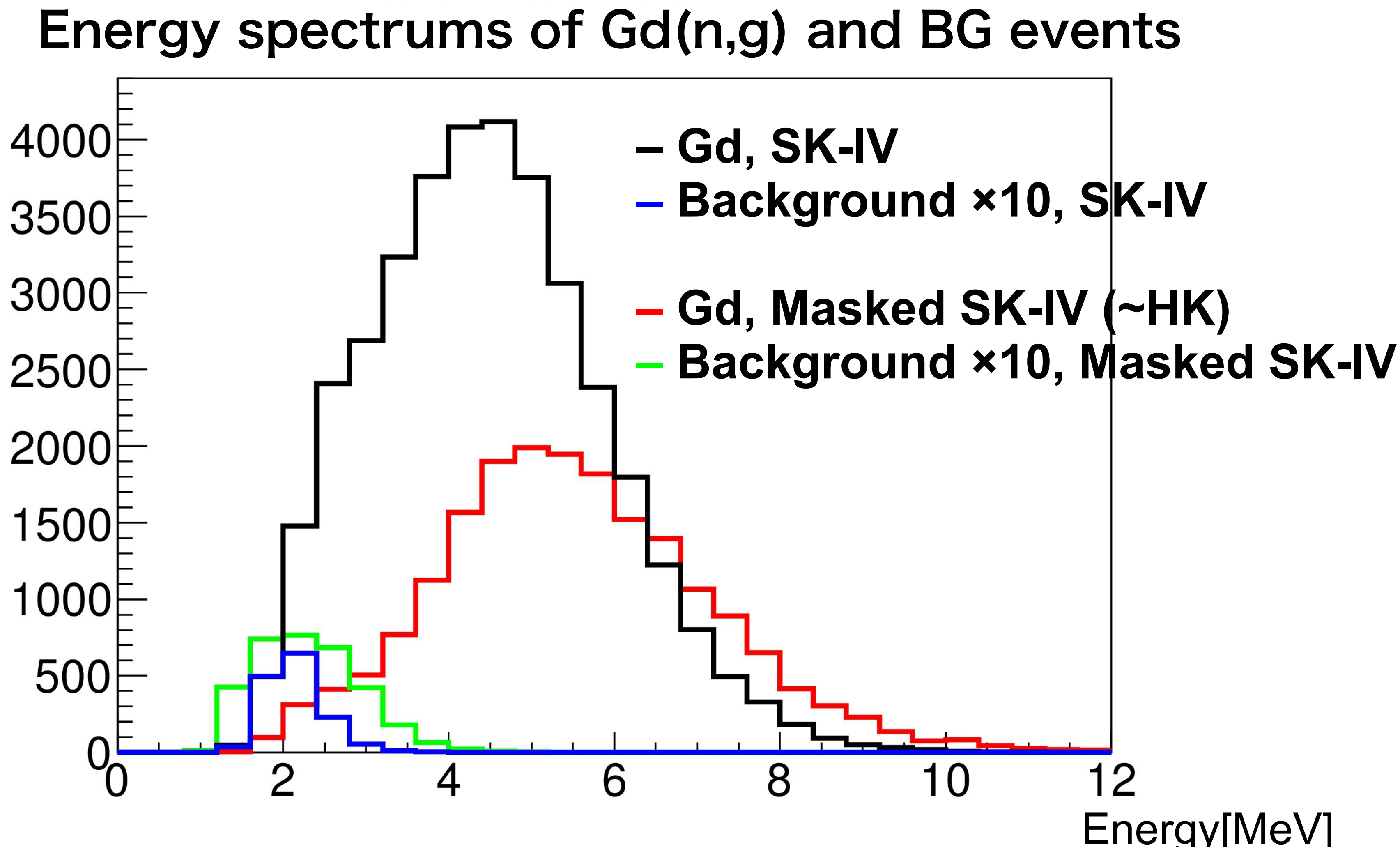


Data set : Background

Super-K IV
- T2K dummy trigger (±500 μsec)
- 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

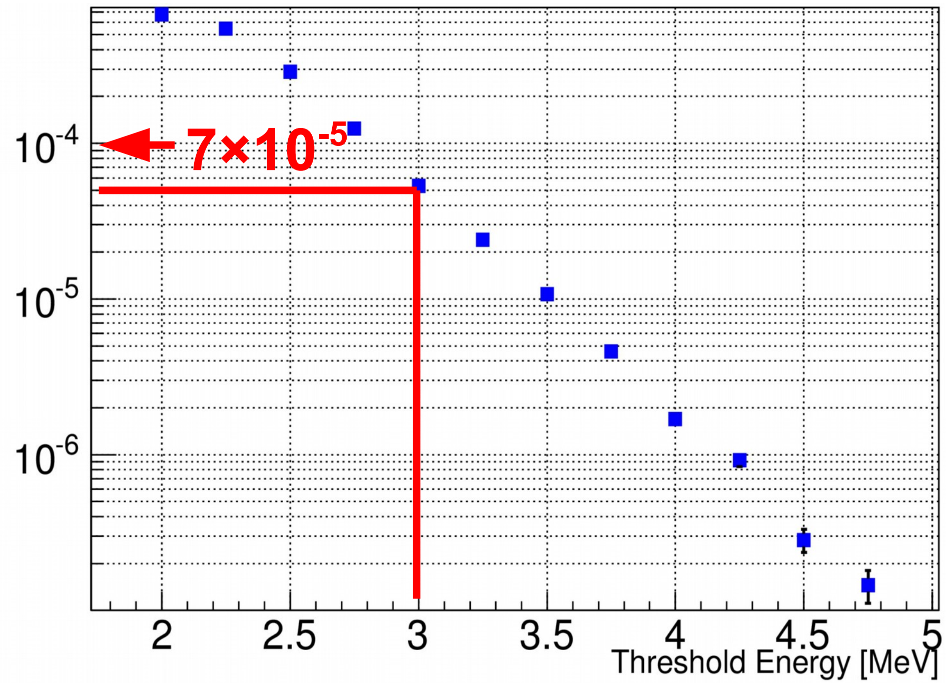


Event selection criteria :

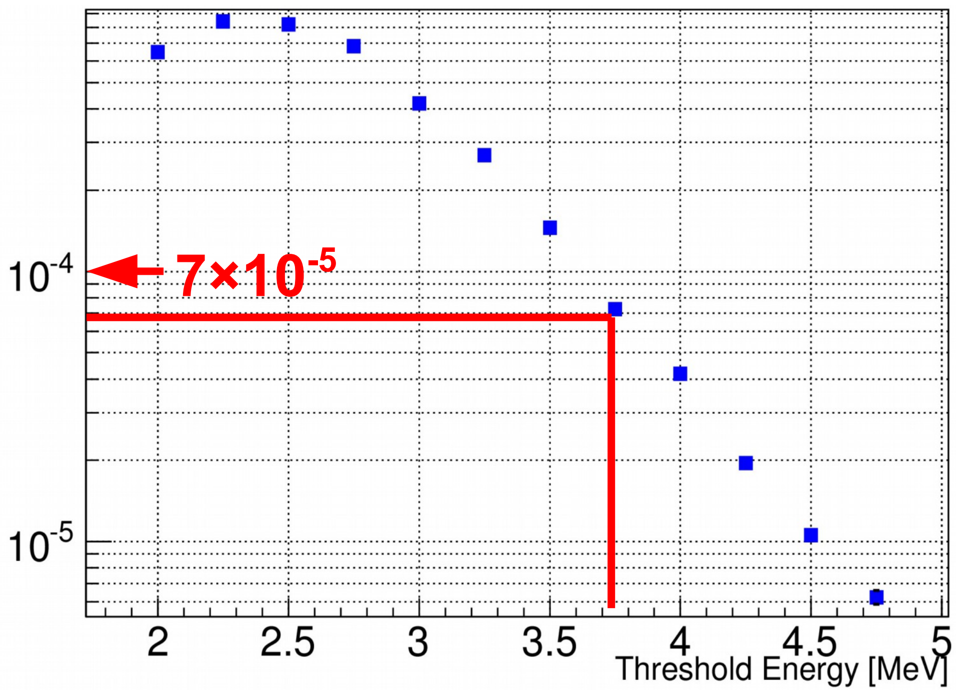
- Distance from source center: R < 2 m
- Event time difference from first trigger: $1.7\mu s < \Delta T < 35\mu s$
- Goodness, Dirks, Cherenkov like cut

BG Reduction Efficiency

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



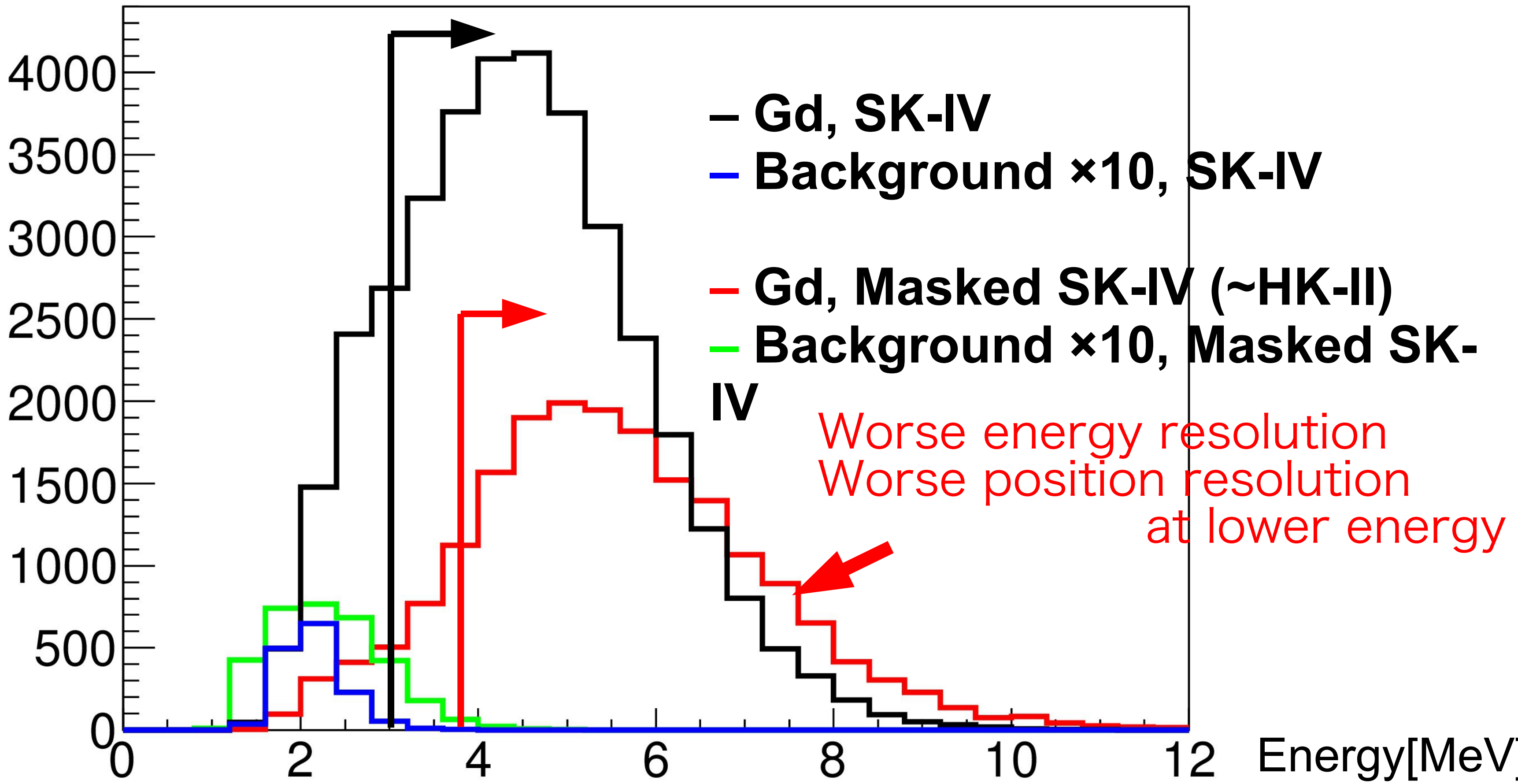
Reduction Efficiency for <2m, 60μs
50% Masked SK-IV



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

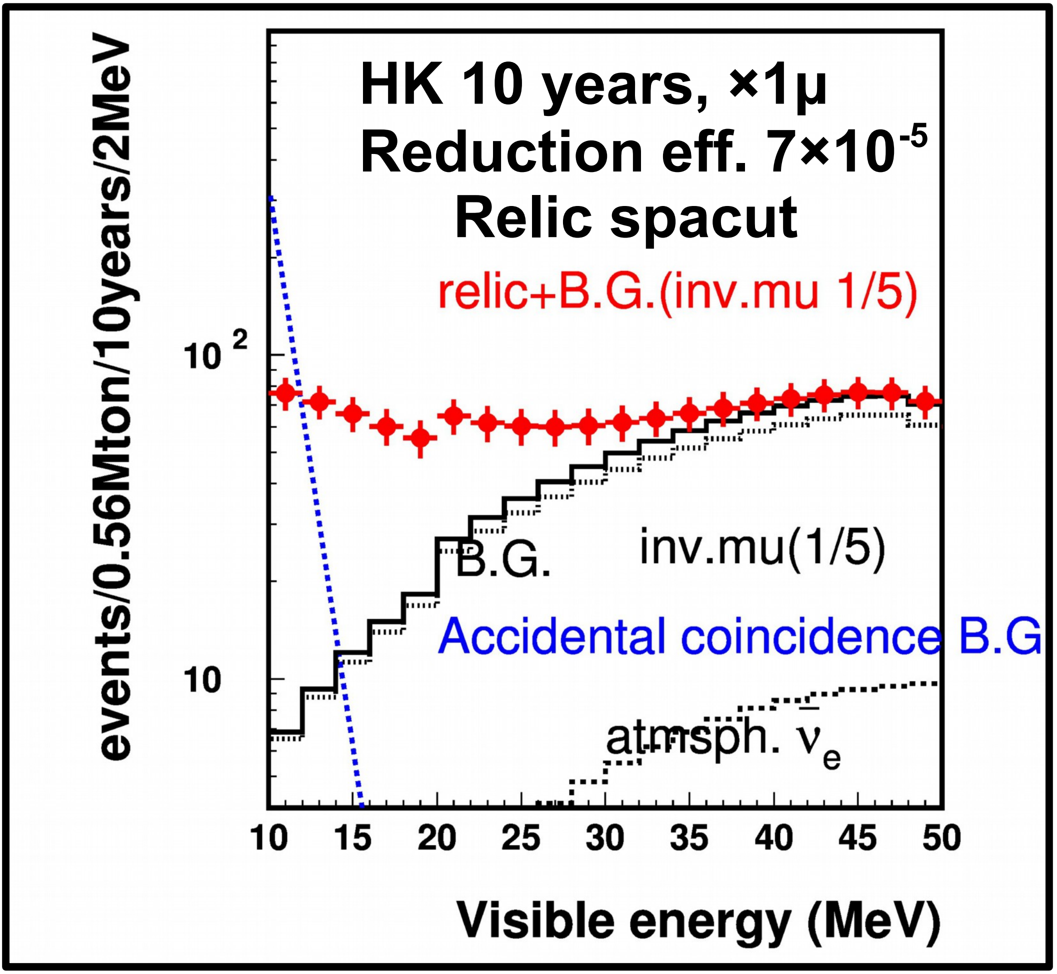


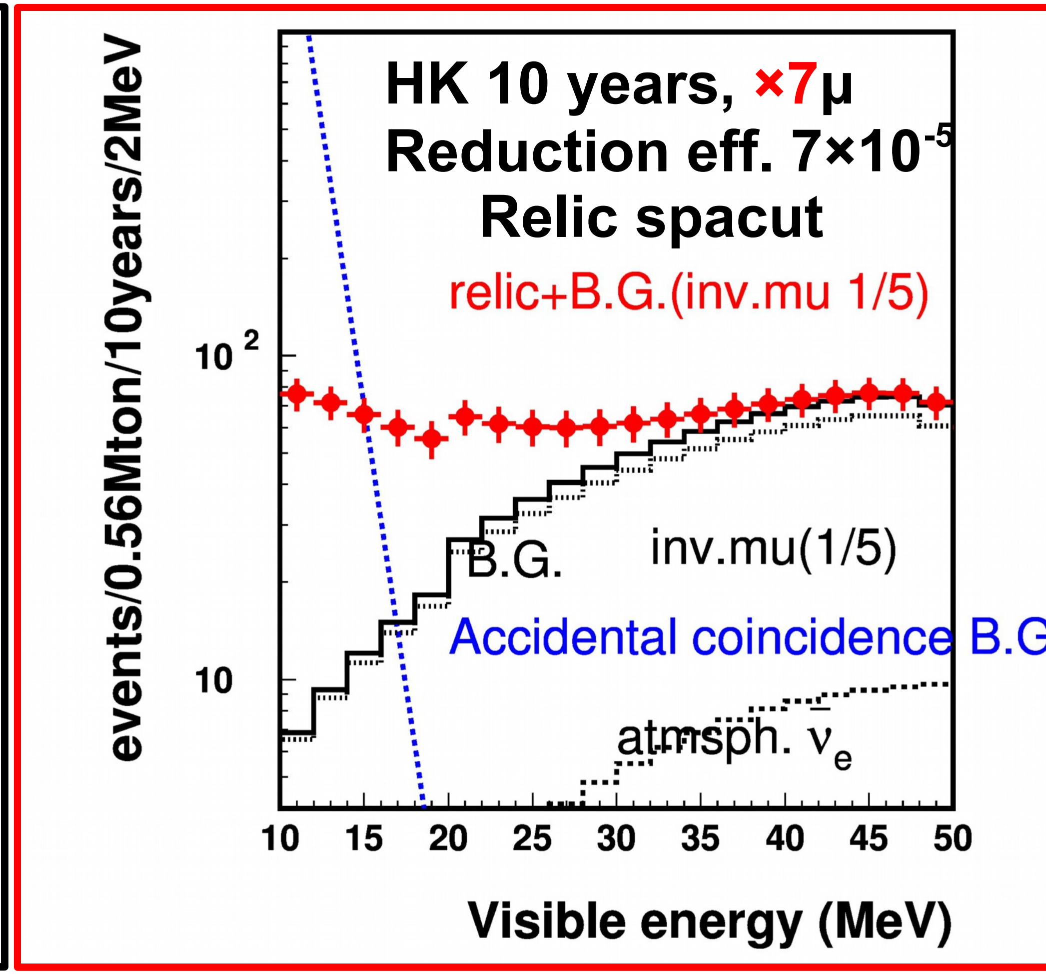
At SK-IV, 92% of Gd(n,γ) events are kept by 3.0 MeV threshold, after R<2.0m selection.

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%.

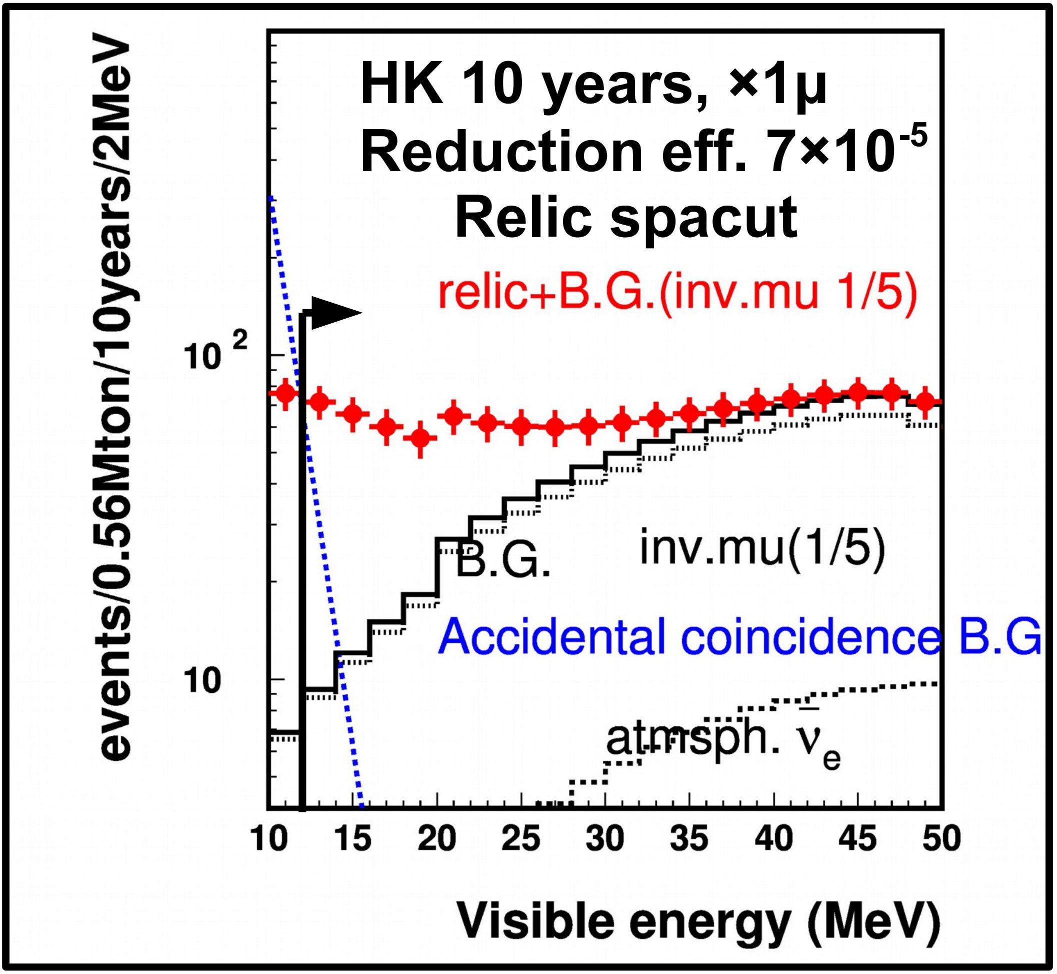
×7μ for HK with Gadolinium

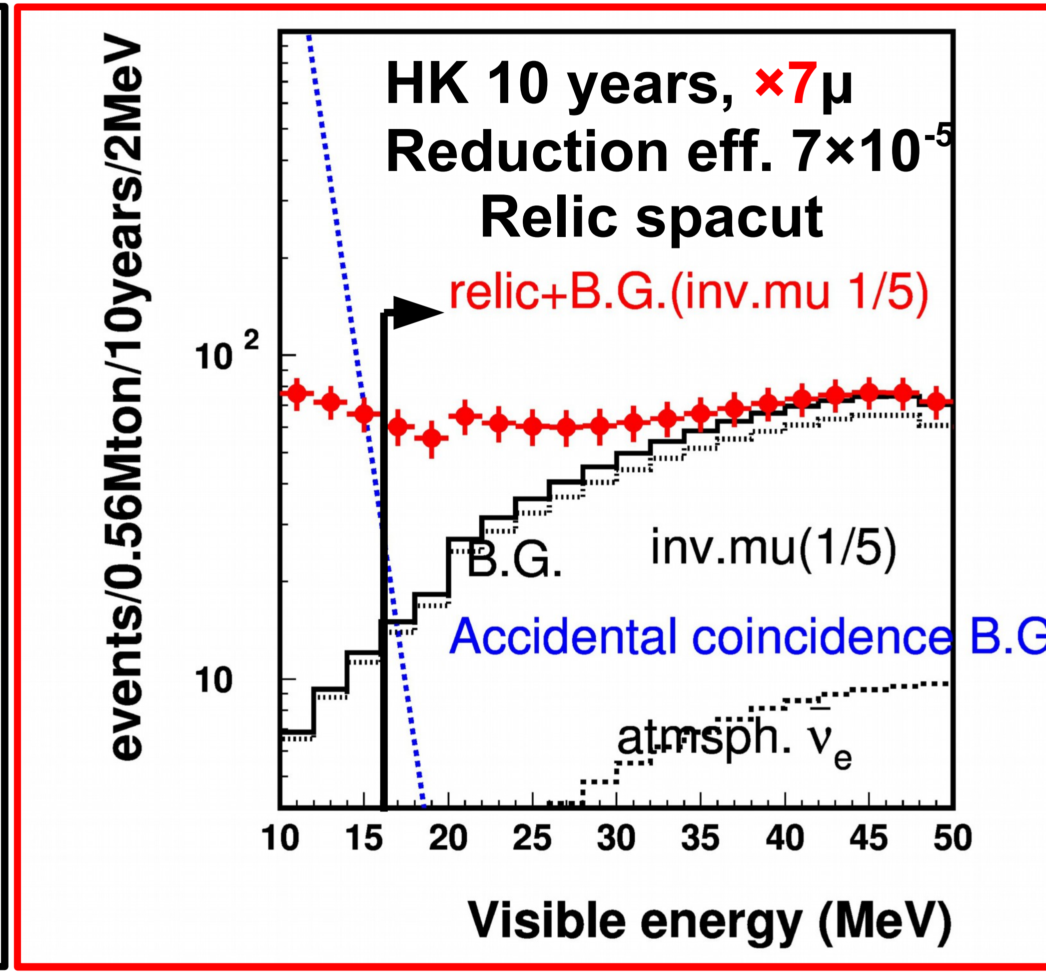




- Considered :
  - Spallation event rate at SK-II solar final sample.
  - ×10 spallation BG for ×7μ case. (factor ×1.4 for relic spacut)
  - 7×10^{-5} reduction by n tagging for accidental coincidence BG.
  - 80% signal efficiency after relic spacut at < 20 MeV.
  - 52% Gd(n,γ) signal efficiency for E >3.75 MeV cut.

×7 μ for HK with Gadolinium





SRN (12-30MeV) = 325 ev.
total BG (12-30MeV)
(not including Accidental coincidence)= 599 ev.

SRN (16-30MeV) = 209 ev.
total BG (16-30MeV)
(not including Accidental coincidence)= 543 ev.

At HK+Gd, the SRN signal exceed the cosmic accidental BG at **>12 MeV (×1 μ)** and at **>16 MeV (×7 μ)**.

With SK-IV + Gd, we would see **> 10 MeV**.

Summary

- The effect of HK location (cosmic muon rate) on SRN search is studied.
  - The significance of SRN will be 7σ after 10 years, if the muon rate is same as SK.
  - In Tochibora, where the muon rate is ×7 of SK, the significance stays 5σ. (In the worst case, 4σ)

  - The Gd option for HK is also studied.
  - The effect of photo coverage 20% is studied.
  - The signal efficiency become 52% for E>3.75 cut.
  - In Tochibora, only >16 MeV can be seen even with Gd.

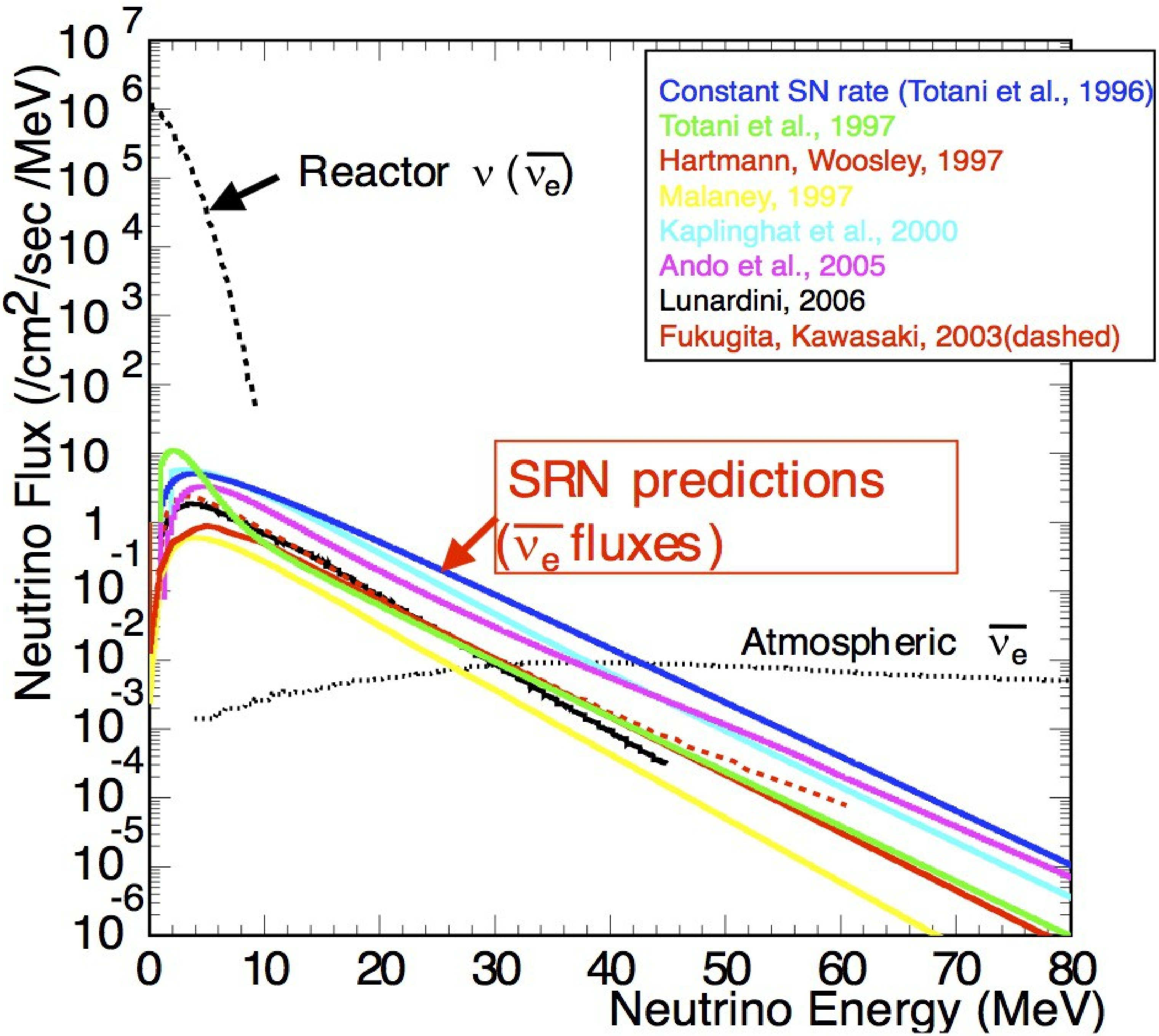
We, Low-E group, prefer the location with less muon background or HK+Gd for SRN.

Summary

without Gd, 10 years	N_events	n σ
$\times 1 \mu$	276	7
$\times 3 \mu$	244	6
$\times 5 \mu$	217	6
$\times 7 \mu$	190	5
$\times 10 \mu$	171	4

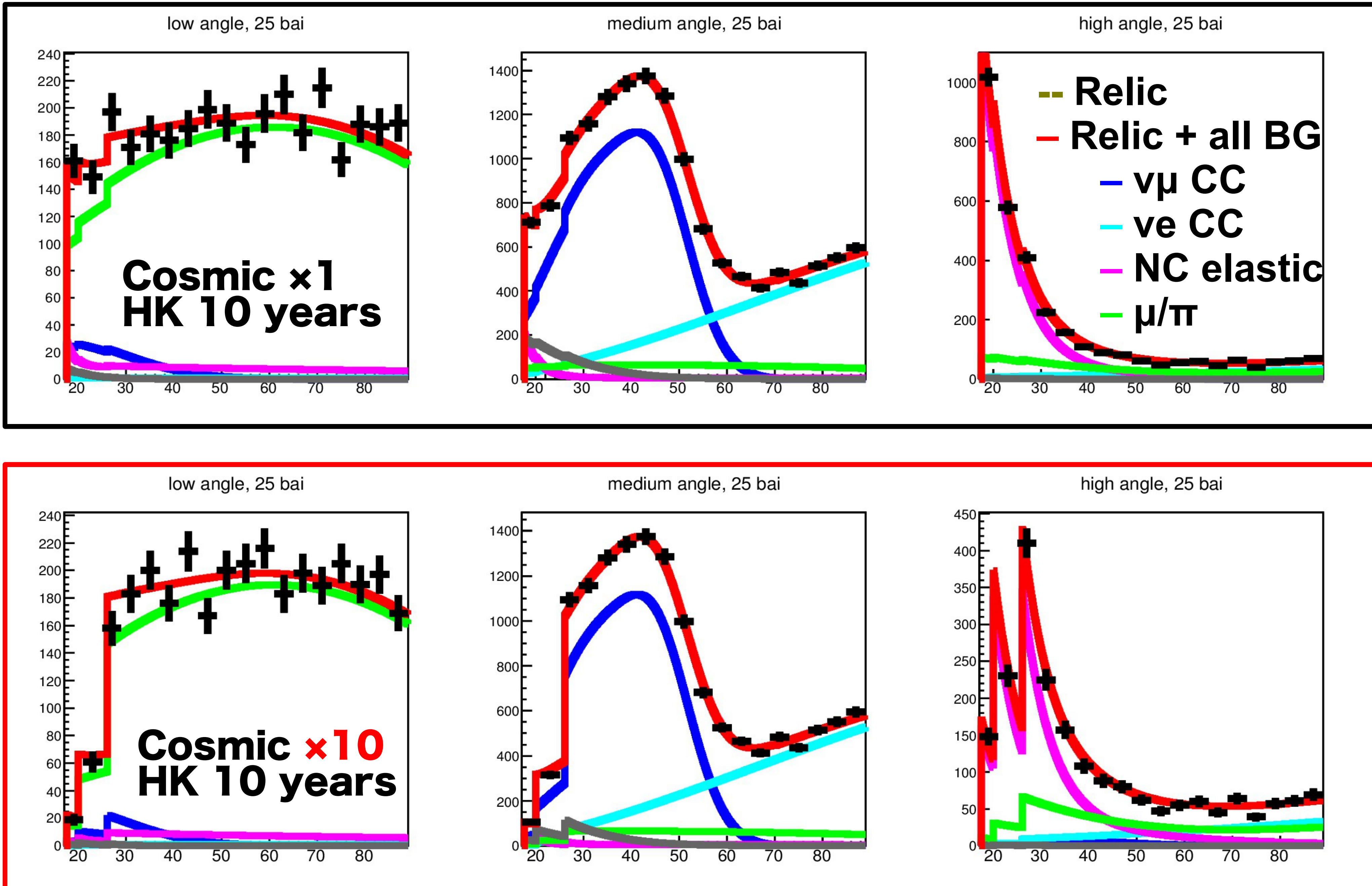
with Gd, 10 years	N_events	N_BG
$\times 1 \mu$	325	599
$\times 3 \mu$	262	574
$\times 5 \mu$	209	543
$\times 7 \mu$	209	543
$\times 10 \mu$	209	543
$\times 7 \mu$ (>20MeV)	209	543

Appendix



Neutrino Flux (/cm^2/sec /MeV)
Neutrino Energy (MeV)
Reactor ν ($\overline{\nu_e}$)
SRN predictions
($\overline{\nu_e}$ fluxes)
Atmospheric $\overline{\nu_e}$
Constant SN rate (Totani et al., 1996)
Totani et al., 1997
Hartmann, Woosley, 1997
Malaney, 1997
Kaplinghat et al., 2000
Ando et al., 2005
Lunardini, 2006
Fukugita, Kawasaki, 2003(dashed)

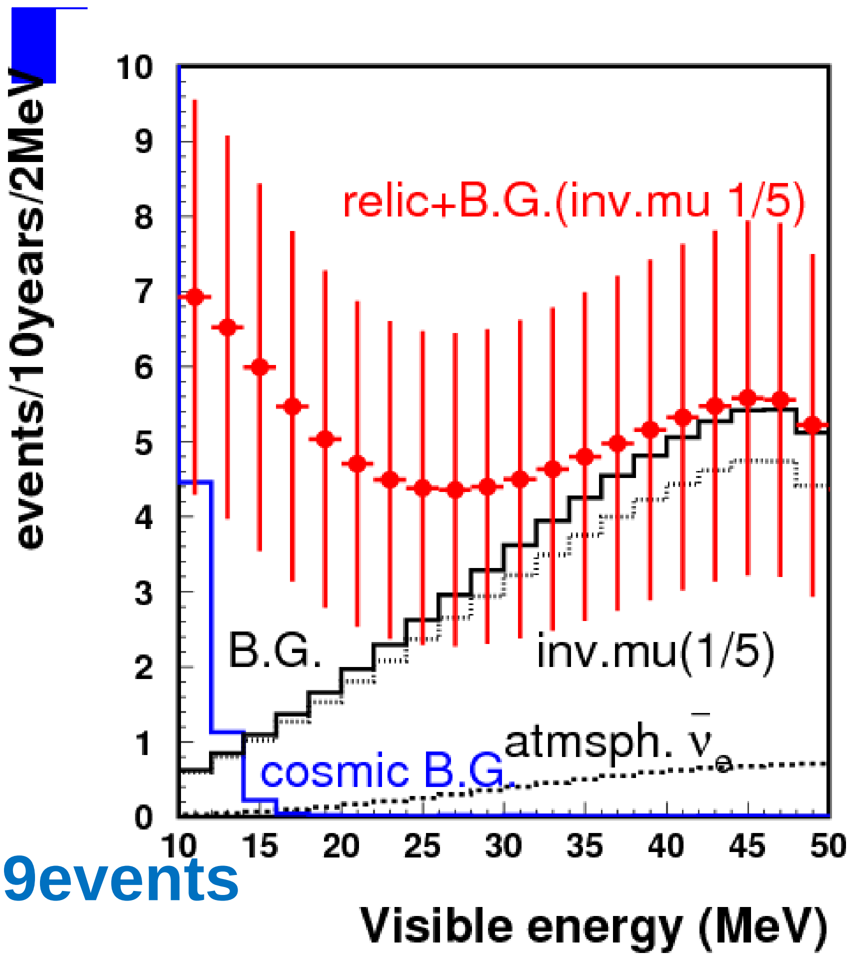
Spectrum Fit (MINUIT2, ROOT)



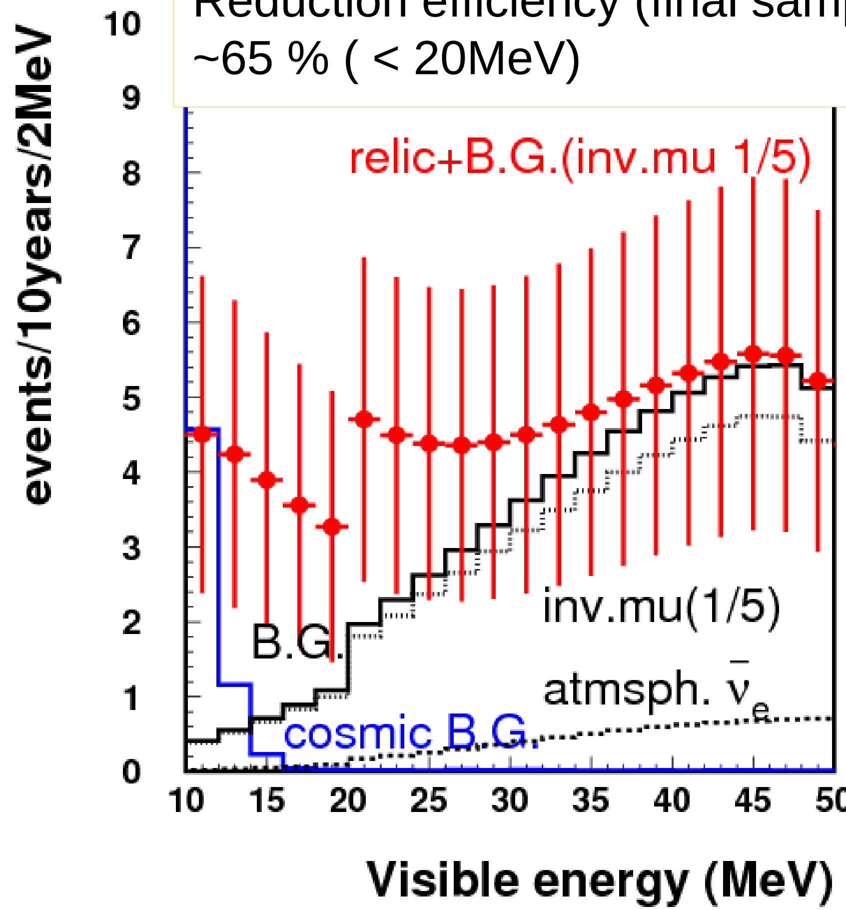
*Takaaki Mori, 2011 09 05

BG estimation (with final sample) @Super-K

Reduction efficiency (final sample):
~65 % (< 20MeV)



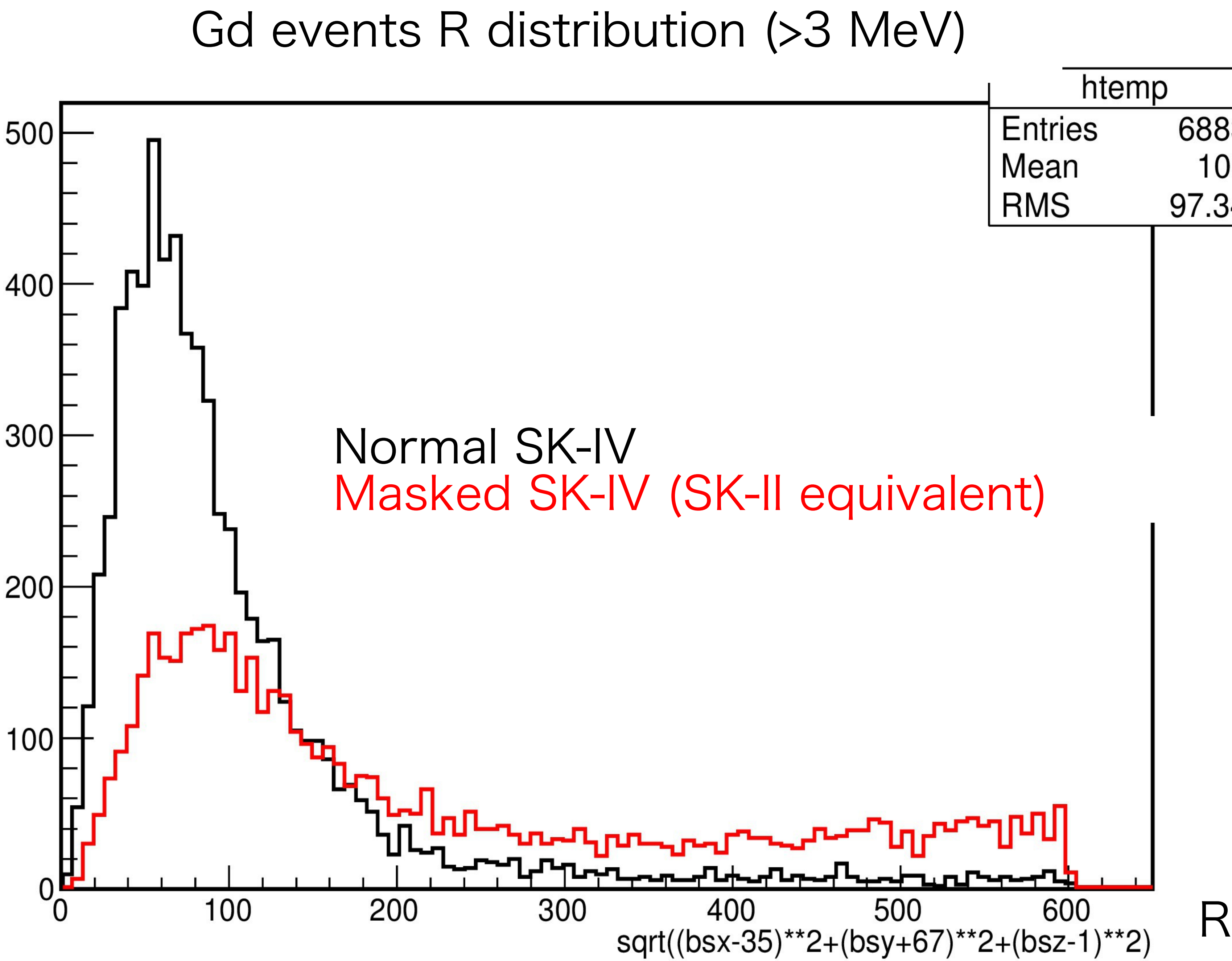
~5.9events



10-30MeV Signal: 33.55 events
B.G. : 33.05 events
15-30MeV Signal: 19.02 events
B.G. : 24.56 events

10-30MeV Signal: 25.03 events
B.G. : 30.72 events
15-30MeV Signal: 15.59 events
B.G. : 22.72 events

Gd in HK


Gd events R distribution (>3 MeV)
htemp
Entries 6883
Mean 105
RMS 97.34
Normal SK-IV
Masked SK-IV (SK-II equivalent)
500
400
300
200
100
0
0
100
200
300
400
500
600
R
sqrt((bsx-35)**2+(bsy+67)**2+(bsz-1)**2)

Efficiency table

Cut条件をSK-IIと同様に保った時のSignal efficiency

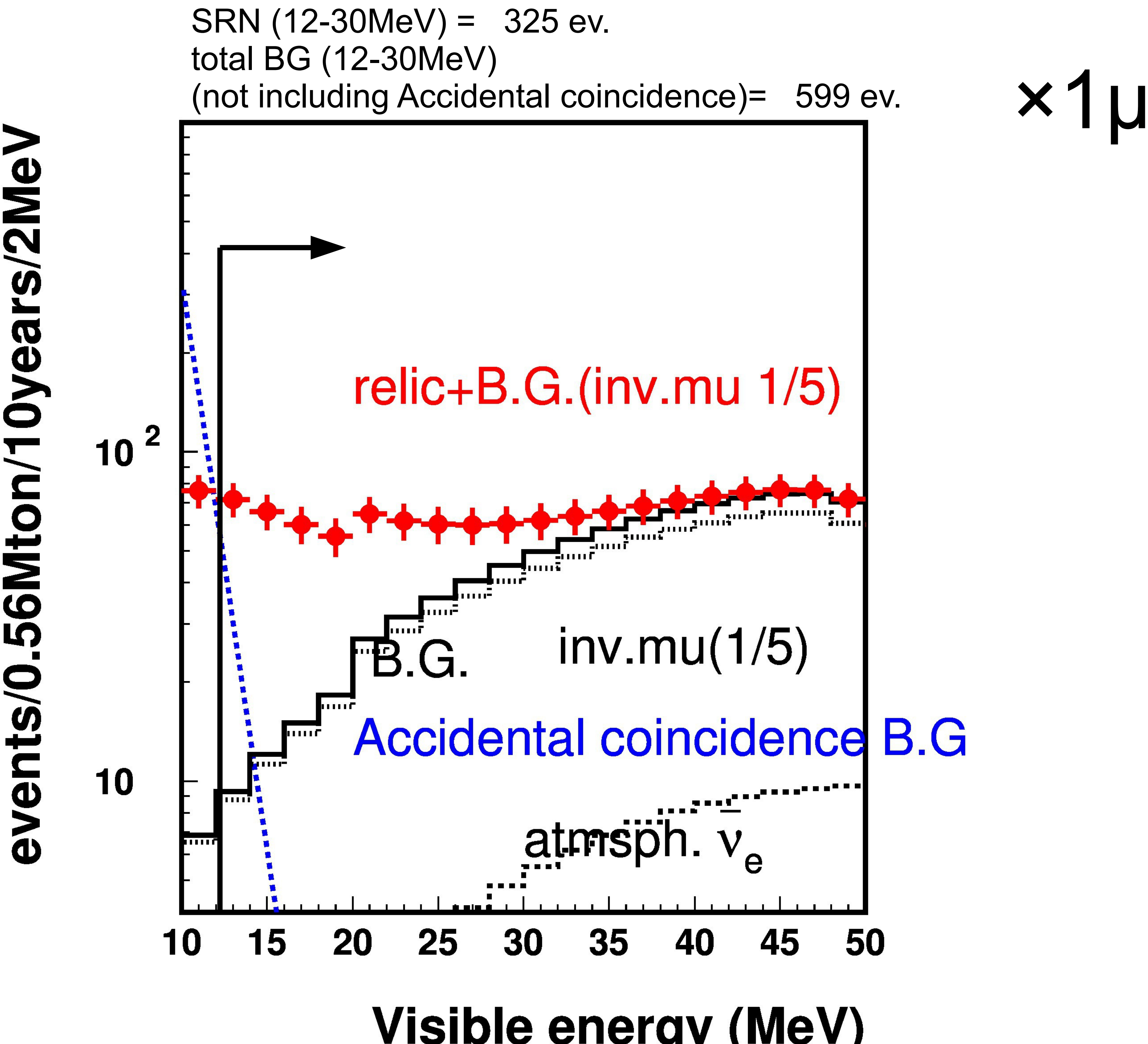
Signal Efficiency	Cosmic μ ×1	×2	×3	×5	×7	×10
17.5-20MeV	81%	65%	52%	33%	21%	11%
20-26MeV	90%	81%	74%	59%	46%	35%

80%キープ時の Reduction efficiecny

17.5-20 MeV	Cosmic μ ×1	×2	×3	×5	×7	×10
Signal Efficiency	80.2%	79%	78%	78%	79%	77%
Spallation events left	6.6%	7.4%	7.5%	8.8%	9.3%	10.0%

TABLE V. 90 % C.L. flux limit ($\bar{\nu}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$), $E_\nu > 17.3$ MeV

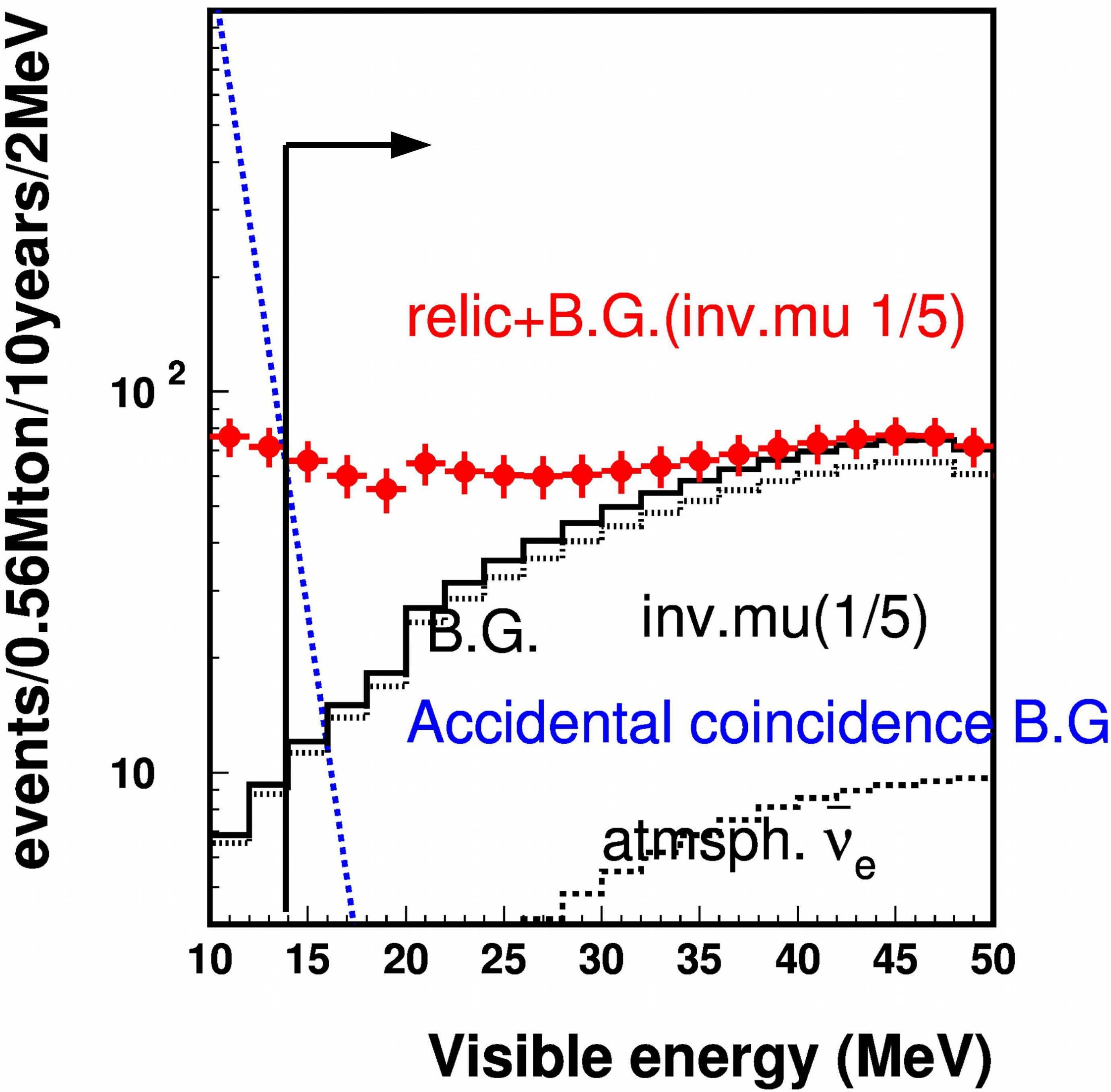
Model	SK-I	SK-II	SK-III	All	Predicted	
Gas Infall (97)	<2.1	<7.5	<7.8	<2.8	0.3	0.18
Chemical (97)	<2.2	<7.2	<7.8	<2.8	0.6	0.35
Heavy Metal (00)	<2.2	<7.4	<7.8	<2.8	< 1.8	1.1
LMA (03)	<2.5	<7.7	<8.0	<2.9	1.7	1
Failed SN (09)	<2.4	<8.0	<8.4	<3.0	0.7	0.41
6 MeV (09)	<2.7	<7.4	<8.7	<3.1	1.5	0.88



SRN (12-30MeV) = 325 ev.
total BG (12-30MeV)
(not including Accidental coincidence)= 599 ev.
×1μ
relic+B.G.(inv.mu 1/5)
B.G.
inv.mu(1/5)
Accidental coincidence B.G
atmsph. $\bar{\nu}_e$
events/0.56Mton/10years/2MeV
Visible energy (MeV)

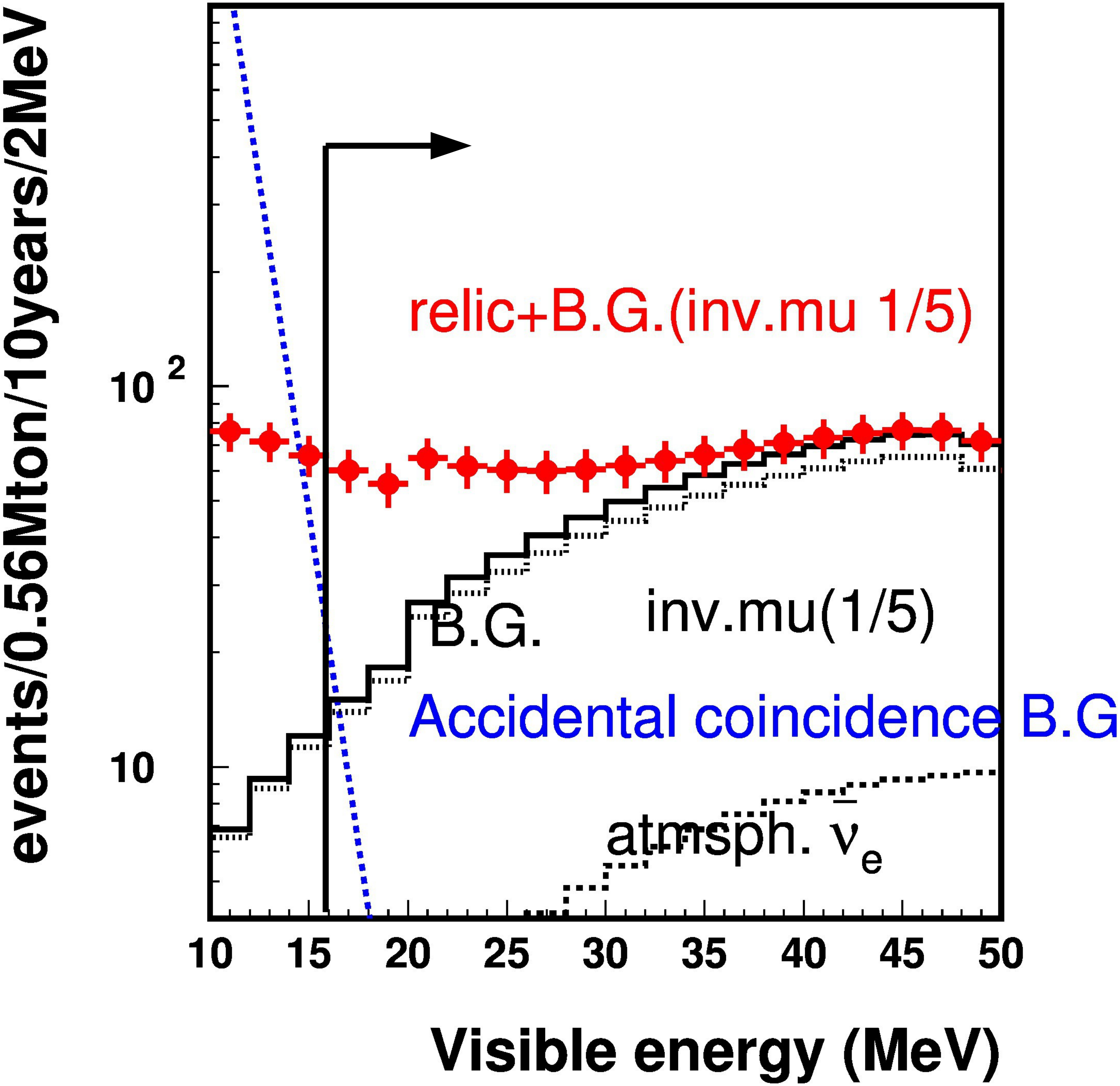
SRN (14-30MeV) = 262 ev.
total BG (14-30MeV)
(not including Accidental coincidence)= 574 ev.

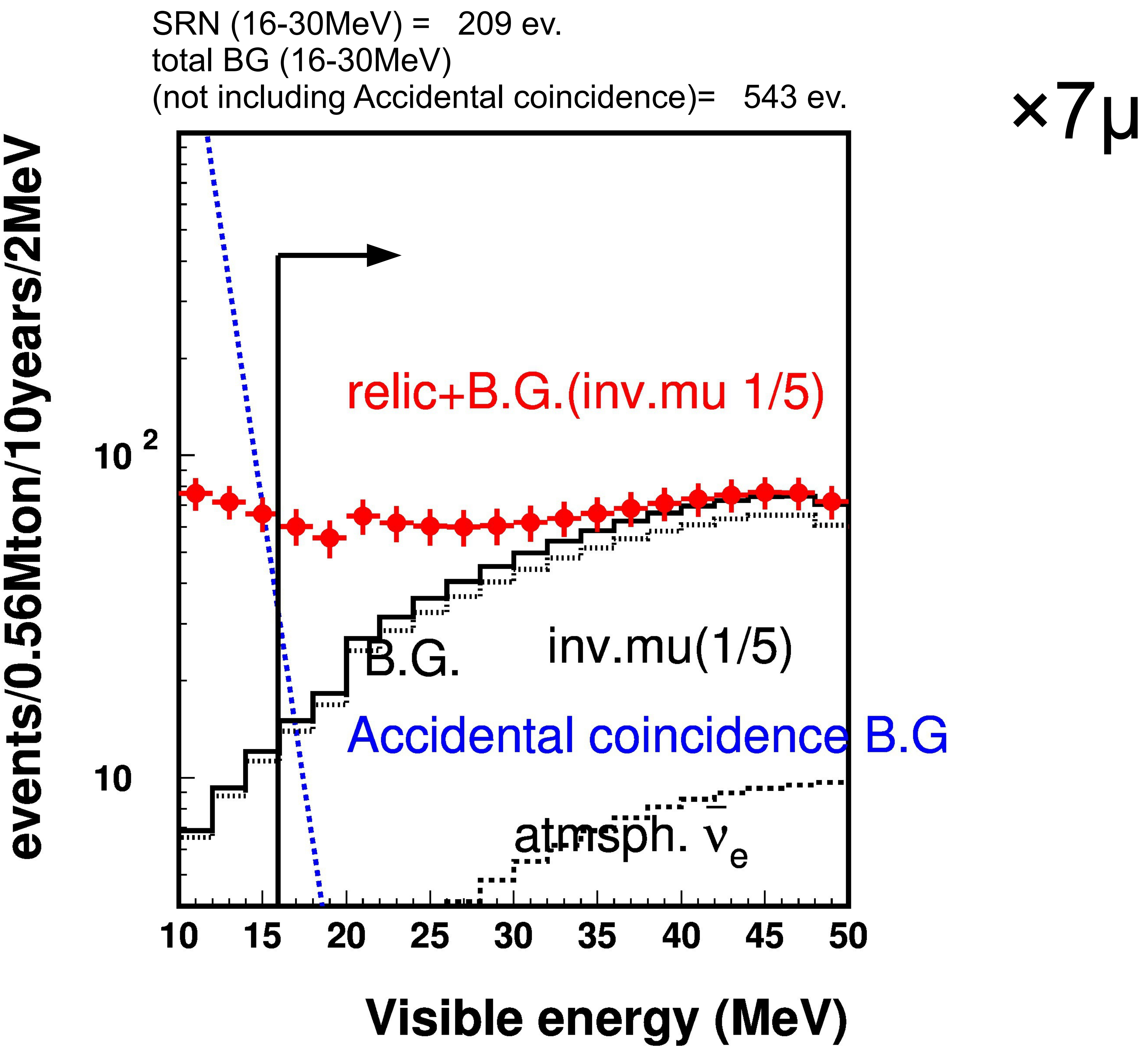
×3μ

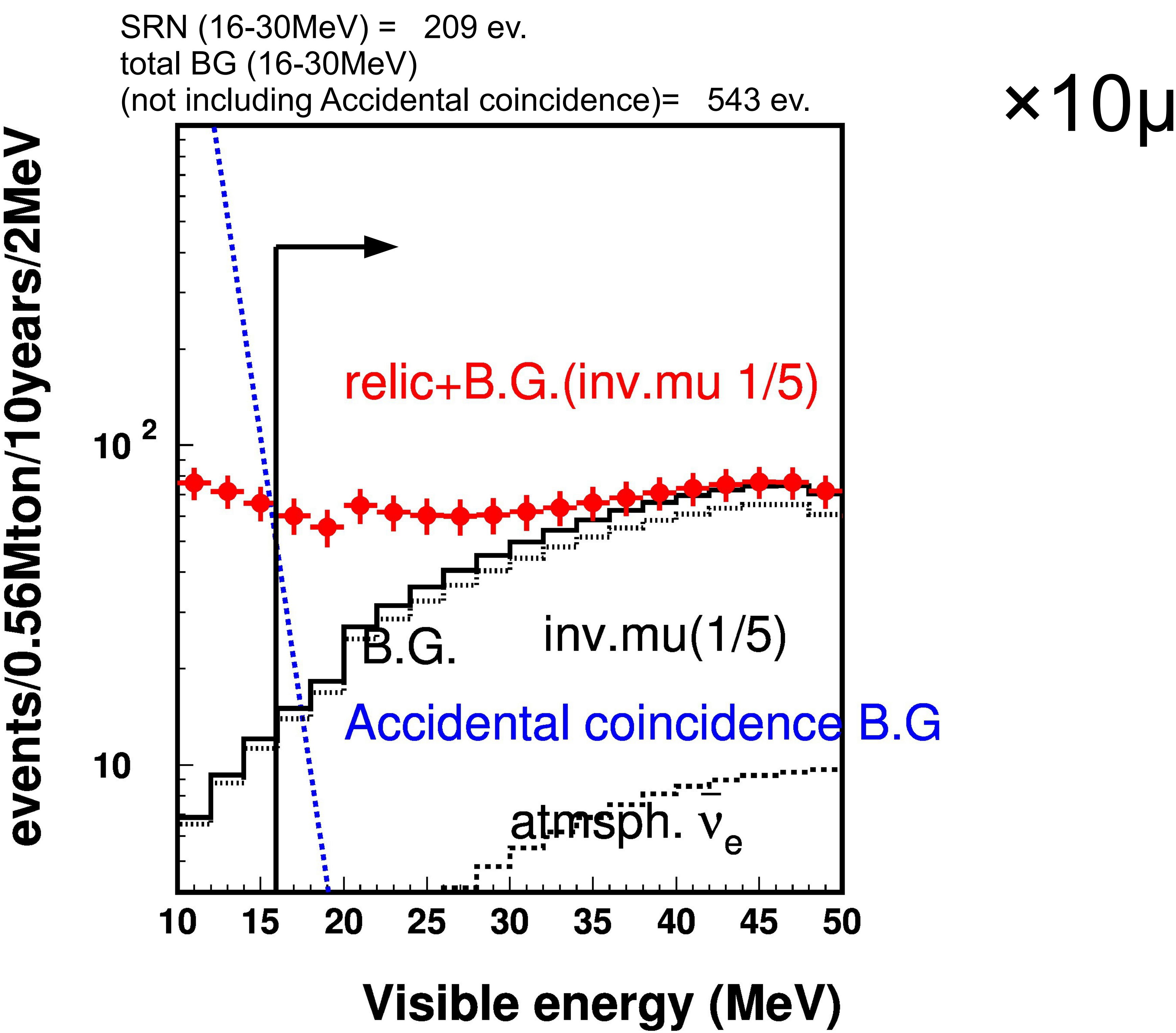


SRN (16-30MeV) = 209 ev.
total BG (16-30MeV)
(not including Accidental coincidence)= 543 ev.

×5μ




SRN (16-30MeV) = 209 ev.
total BG (16-30MeV)
(not including Accidental coincidence)= 543 ev.
×7μ
relic+B.G.(inv.mu 1/5)
B.G.
inv.mu(1/5)
Accidental coincidence B.G
atmsph. $\bar{\nu}_e$
events/0.56Mton/10years/2MeV
10^2
10
10
15
20
25
30
35
40
45
50
Visible energy (MeV)


SRN (16-30MeV) = 209 ev.
total BG (16-30MeV)
(not including Accidental coincidence)= 543 ev.
×10μ
events/0.56Mton/10years/2MeV
relic+B.G.(inv.mu 1/5)
B.G.
inv.mu(1/5)
Accidental coincidence B.G
atmsph. $\bar{\nu}_e$
10
10 2
10
15
20
25
30
35
40
45
50
Visible energy (MeV)