14-JAN-2013 @ 2nd HK open meeting

Spallation background

Yasuo Takeuchi
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- Low-energy backgrounds in SK
- Spallation BG
- Dark rate & Detector resolutions

(All the energies in this slide are electron total energy)

Low-energy backgrounds in SK

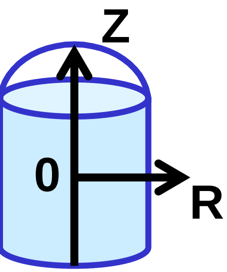
Spallation is dominant BG source in ~10-20MeV

Misfit

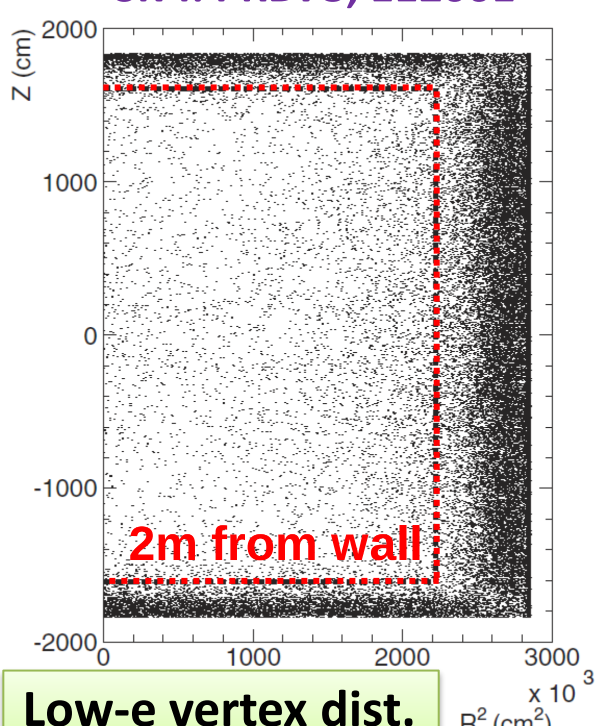
External gamma

Radon, Misfit, External gamma, etc.

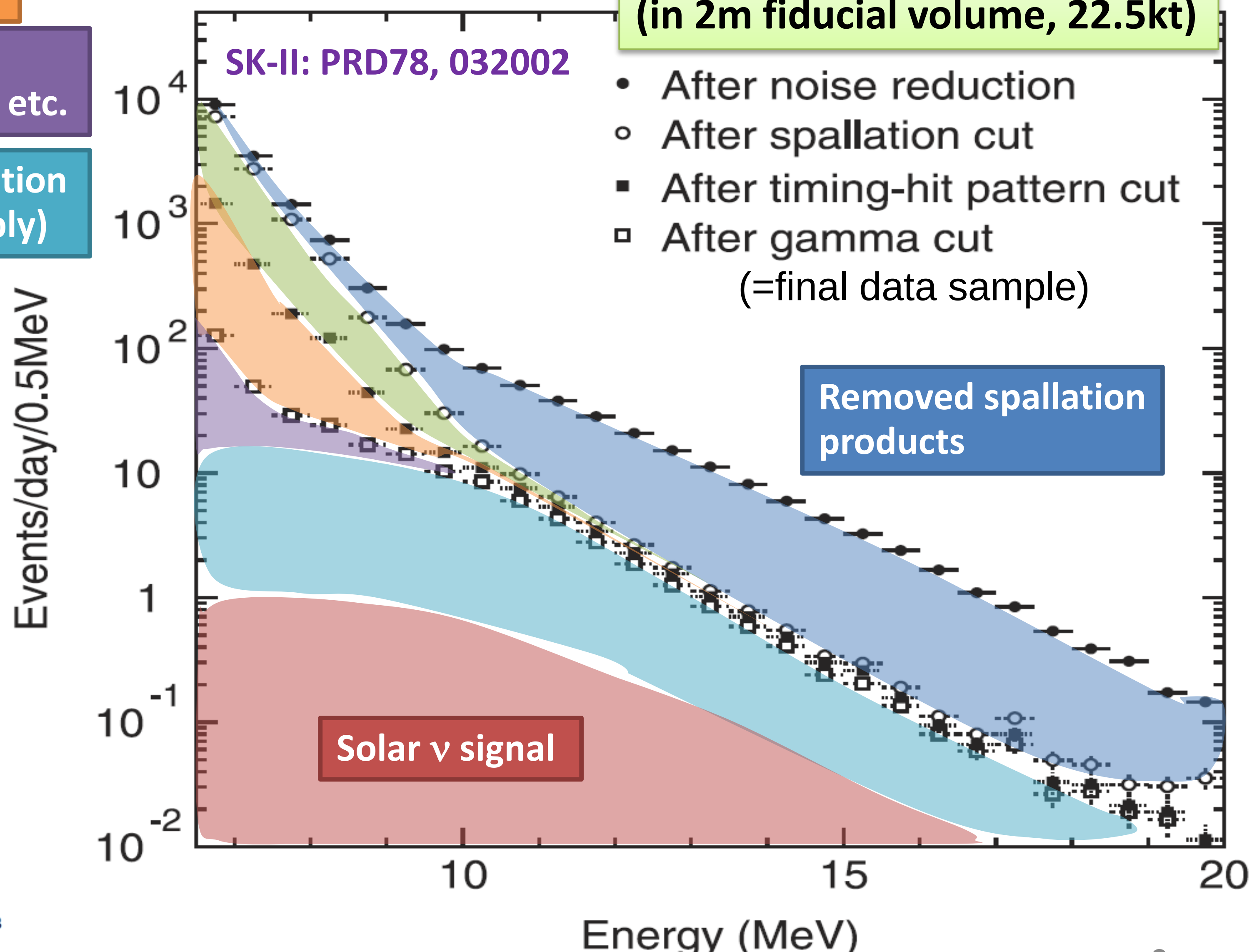
Remaining spallation products (probably)



SK-I: PRD73, 112001



Low-e vertex dist.



Spallation (in water)

SK SRN: PRD85, 052007

- Cosmic-ray muons interact with oxygen nuclei in the water and produce various radio active isotopes.
  →**Spallation**
- Correlation with parent muon
  – Time, Position
- Energy up to ~20MeV
  – Overlap with solar ν (Y. Koshio)
- **Spallation products will be increased in HK due to high cosmic-ray muon flux.**

$\tau_{1/2}$ and E_{max} of spallation products in water

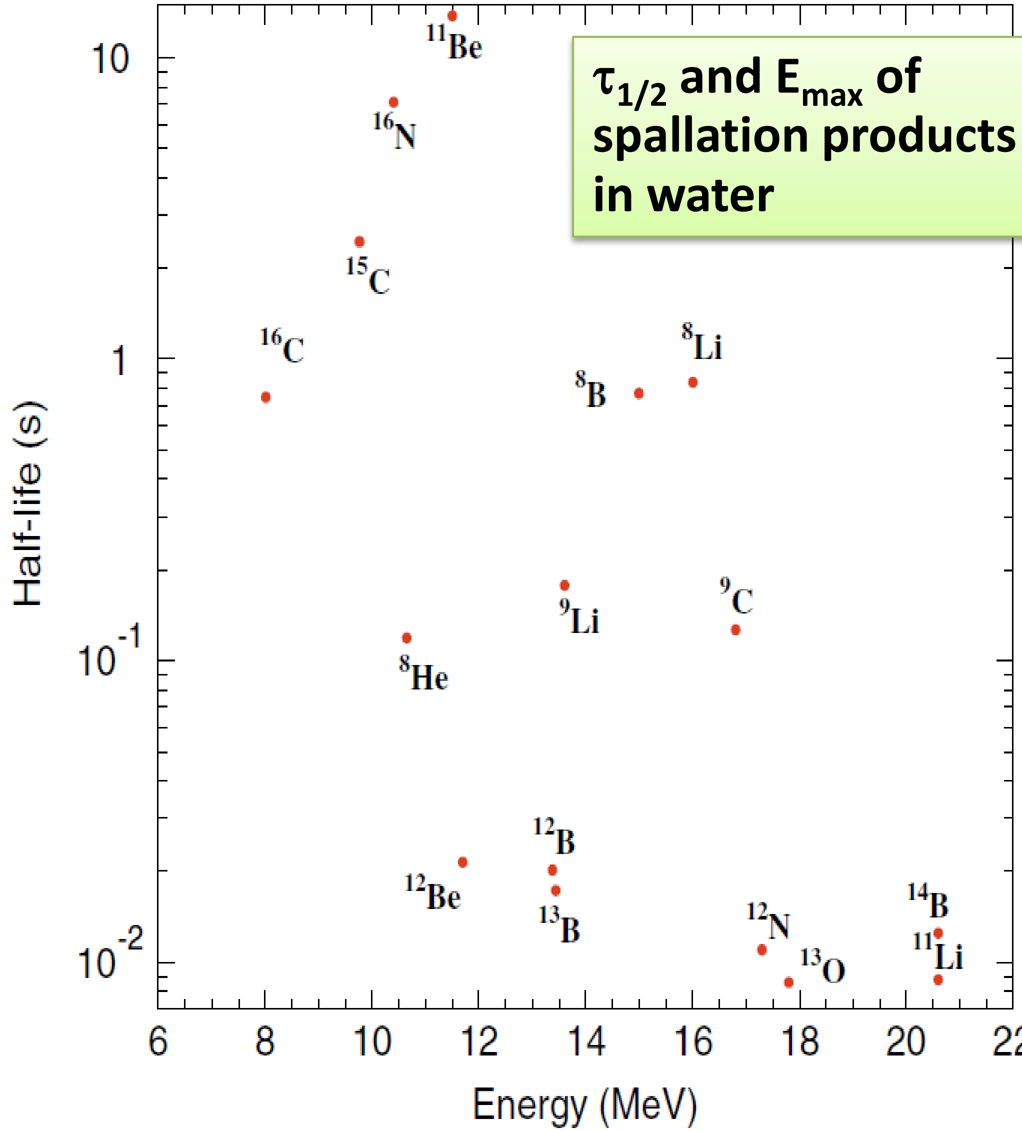
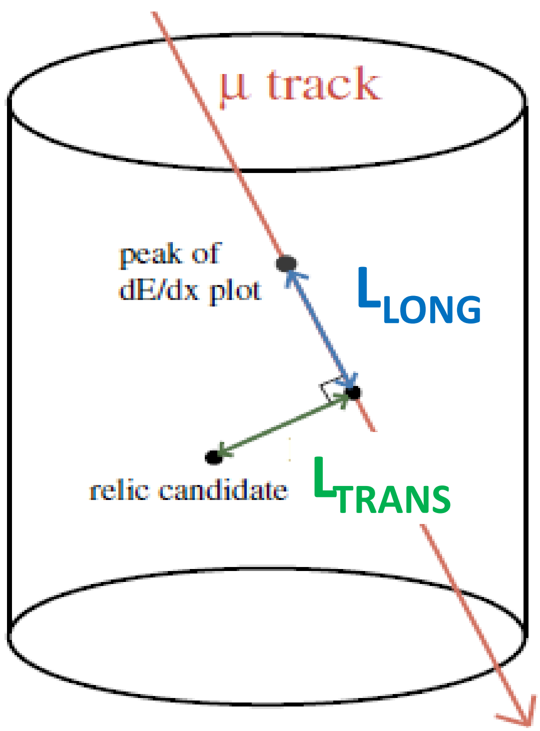


FIG. 5 (color online). Half-lives and event end-point energies of spallation products expected to occur in pure water. Lower energy events trend to longer decay times.

Spallation cut in SK

- Likelihood method is used to reduce spallation products in SK
- "Solar spallation cut" (in PRD73, 112001)
  - *Likelihood* = PDF(Q_{RES}) * PDF(ΔT) * PDF(L_{TRANS})
- "(supernova) relic spallation cut" (in PRD85, 052007)
  - *Likelihood* = PDF(Q_{PEAK}) * PDF(ΔT) * PDF(L_{TRANS}) * PDF(L_{LONG})
- Improved likelihood function is used in "relic spallation cut"



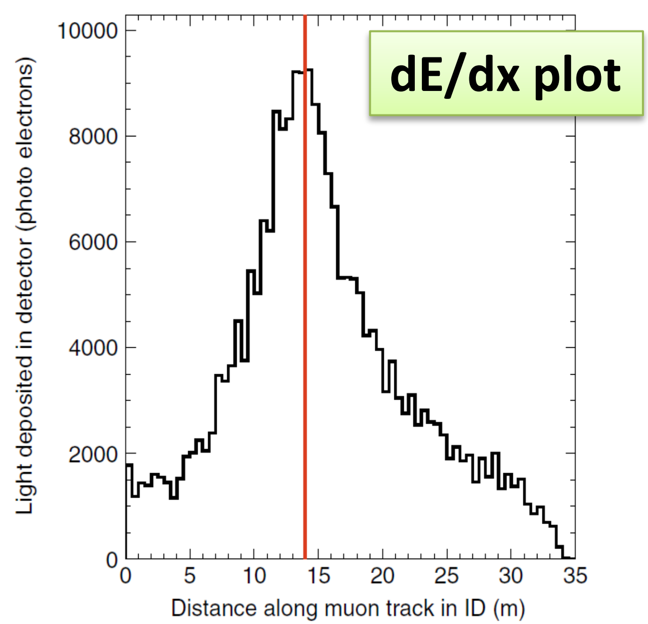


FIG. 2 (color online). Example of a dE/dx plot. The red line indicates where along the muon track the candidate was reconstructed. This example has particularly good correlation.

SK SRN: PRD85, 052007

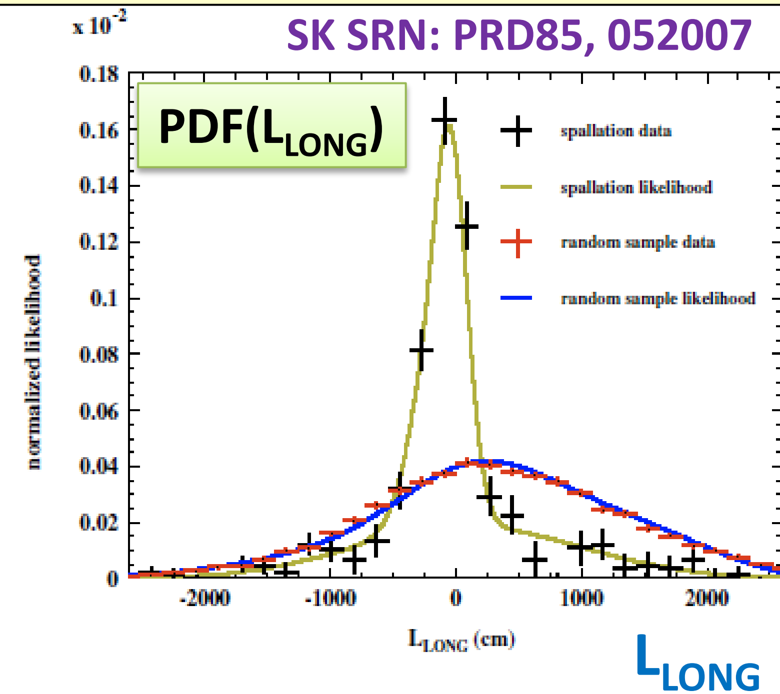
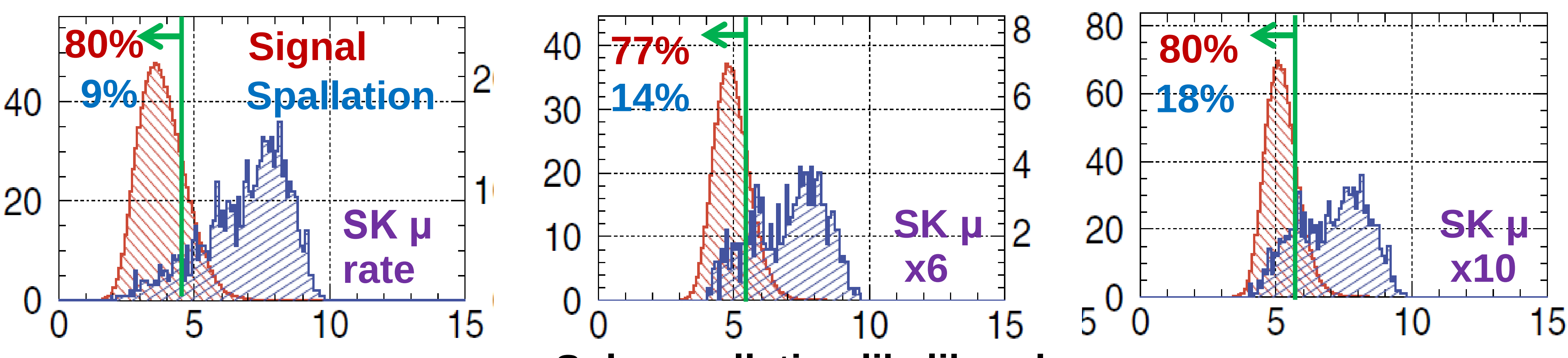


FIG. 4 (color online). SK-I/III data with likelihood functions overlaid for single through-going muons. Top shows transverse distance; bottom shows longitudinal distance.

Our estimation so far

arXiv:1109.3262 (HK LOI)
Poster 34-1 @NEUTRINO2012
Y. Koshio @1st HK open meeting

- So far, "solar spallation cut" and SK-I/III data are used.
  - The density of spallation products: x6~7
  - Increase by spallation cut: x3 at most
  - The density of the remaining spallation products will be increased by a factor of 20 at most in HK



Updates

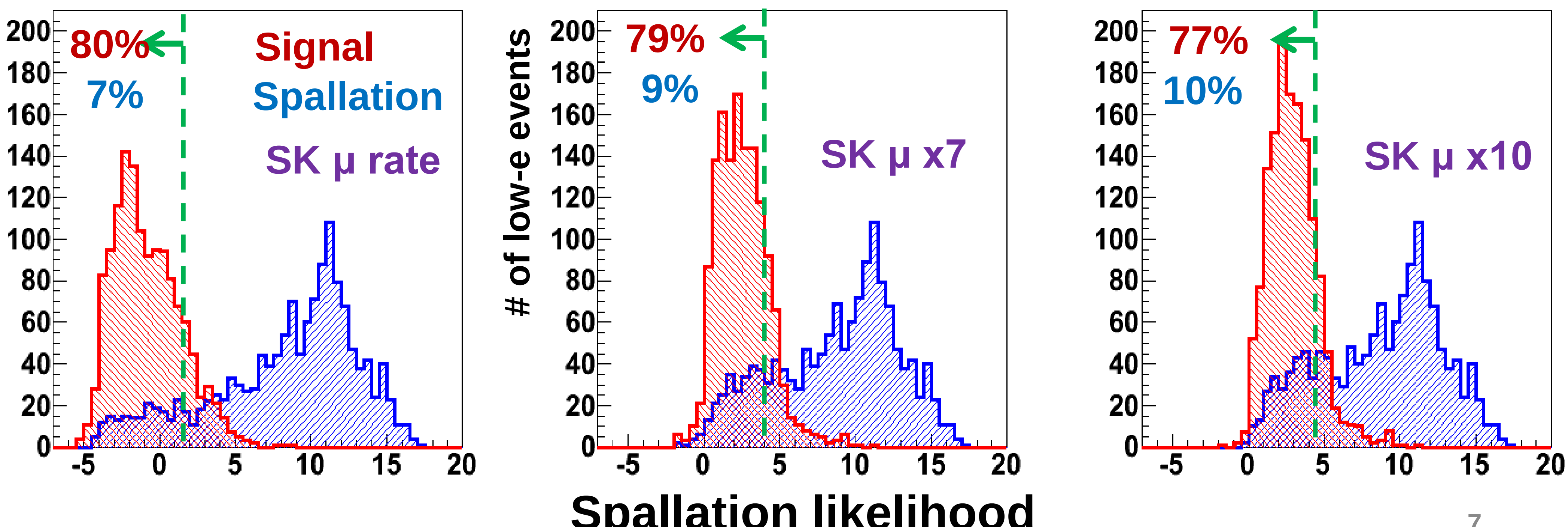
This study was done by T. Yano

- Use **whole SK-II data** with 17.5 MeV < E < 26 MeV
  - 19% photo coverage
  - Previous: SK-III (40% coverage), E>12MeV, 1 day
- Apply a basic **relic spallation cut** under x1~x10 muons (mu*1 ~ mu*10)
  - Just use SK-II likelihood functions and partial cut criteria. Optimization is not done yet.
  - Previous: solar spallation cut (mu*1 ~ mu*30)

Note:
1. Unit of the muon rate is the muon flux in SK detector(=mu*1)
2. Assumed current HK site corresponds to mu*6~7, based on the density of the spallation products, instead of real muon flux in HK site (~mu*10)
3. Some non-spallation BG, like solar ν, are still remaining.

Typical likelihood distribution

- SK-II data 17.5-26MeV
- Spallation: SK-II data before spallation cut
- Signal: random combination between low-e & muon events.
- The green lines are not accurate (cut condition is not a line on the plot)



Remaining spallation events

- **Keep ~80% signal efficiency in 17.5 – 20 MeV**
  - Omit some cuts (Dt, Lt, gof cuts), then just use likelihood distribution.
  - At moment, we assumed <17.5 MeV region is same

	Mu*1	Mu*2	Mu*3	Mu*5	Mu*7	Mu*10
Signal efficiency	80%	79%	78%	78%	79%	77%
Remaining spallation products	7%	7%	8%	9%	9%	10%

Factor ~1.4 increase

Stat. errors are ~10%
Used for Solar study (Y. Koshio)

Cf.: solar spallation cut: factor ~3 increase

Signal efficiency

- **Keep SK-II cut criteria**
  - At moment, we assumed the remaining spallation events are negligible in HK (same as SK-II detector)

	Mu*1	Mu*2	Mu*3	Mu*5	Mu*7	Mu*10
17.5-20MeV	81%	65%	52%	33%	21%	11%
20-26MeV	90%	81%	74%	59%	46%	35%

Used for SN relic study (T. Yano)

Summary of spallation study

- **Expected increase of the spallation background density will be about 10 (for solar ν). (Previous = ~20)**
  - **The density of spallation products: x6~7 (same)**
  - **Increase by spallation cut: x1.4 (updated)**

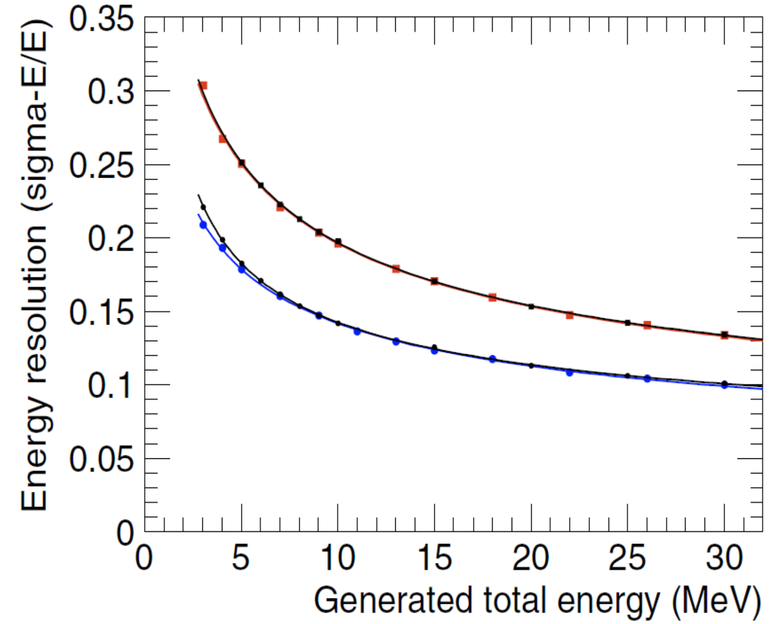
Dark rate & detector resolutions

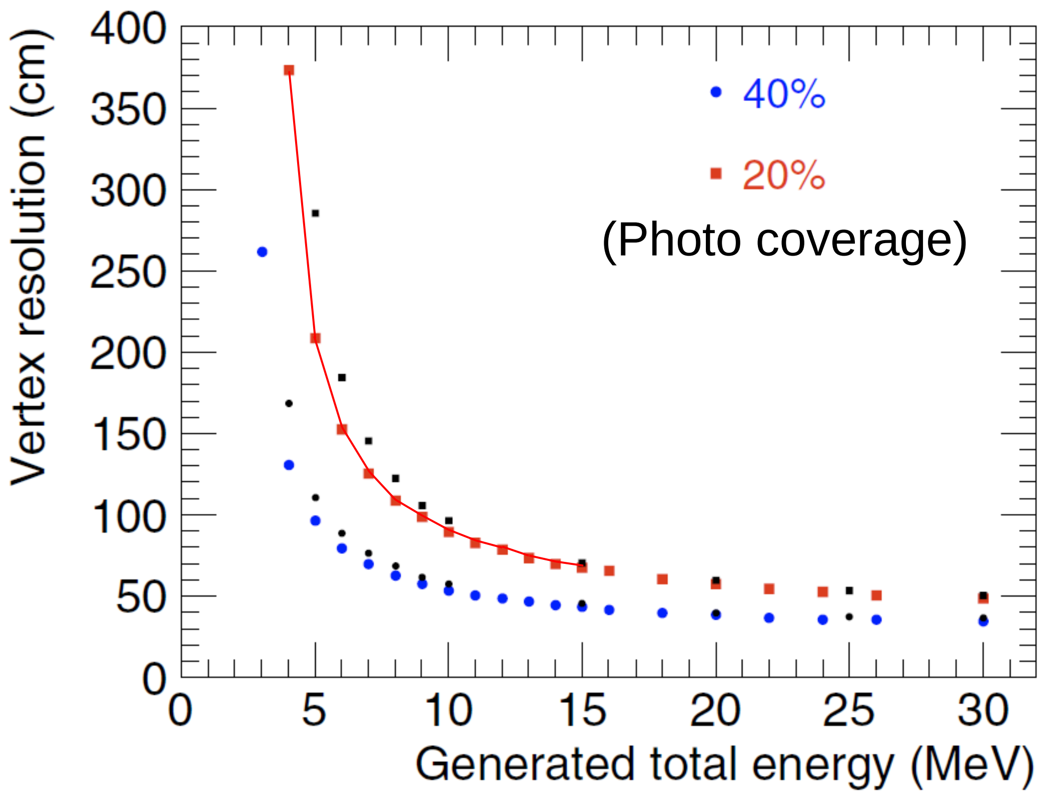
- By increasing the dark rate artificially, event reconstruction quality were studied.

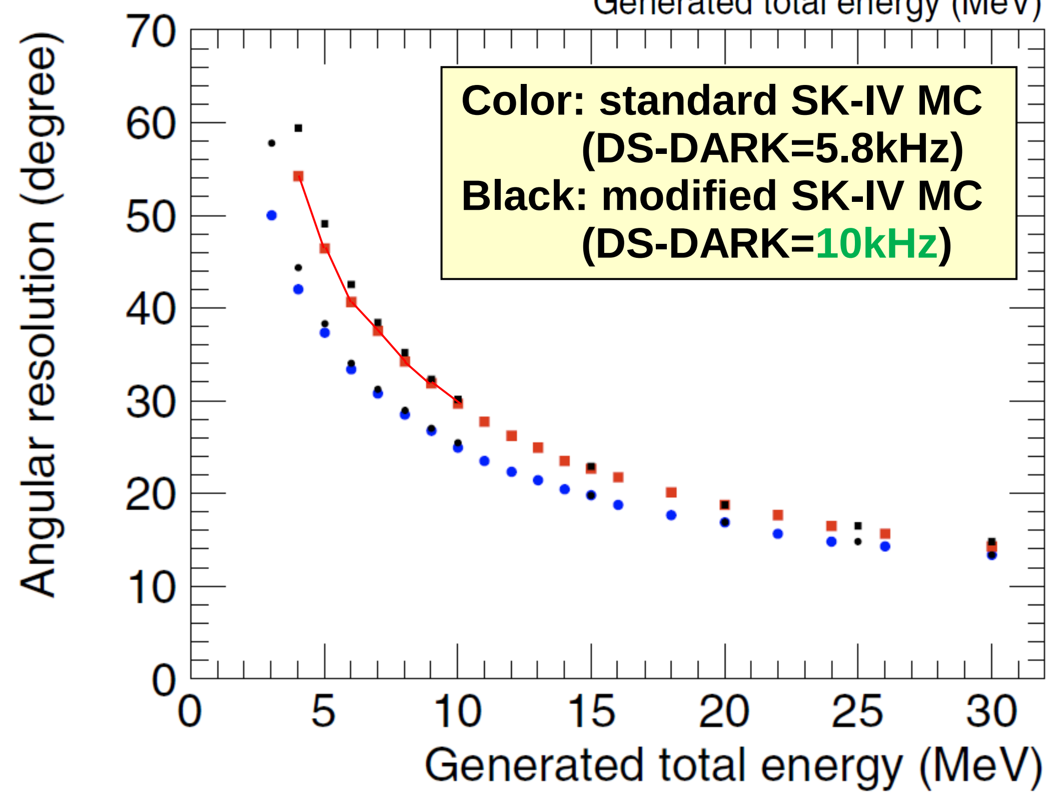
1. Use SK-IV detector simulation
   - Dark rate parameter (DS-DARK) is increased
     - Observed dark rate in SK-IV = DS-DARK/1.27 (kHz)
2. Use SK-I data
   - 5 MeV LINAC & background data

Expected resolutions for an electron

- **Use SK-IV detector simulation**
- **Inside 2m fid. vol.**
- **Photo coverage was changed by masking about half PMTs in SK-IV**
- **Vertex & angular resolutions will be affected by the high dark rate sensors.**



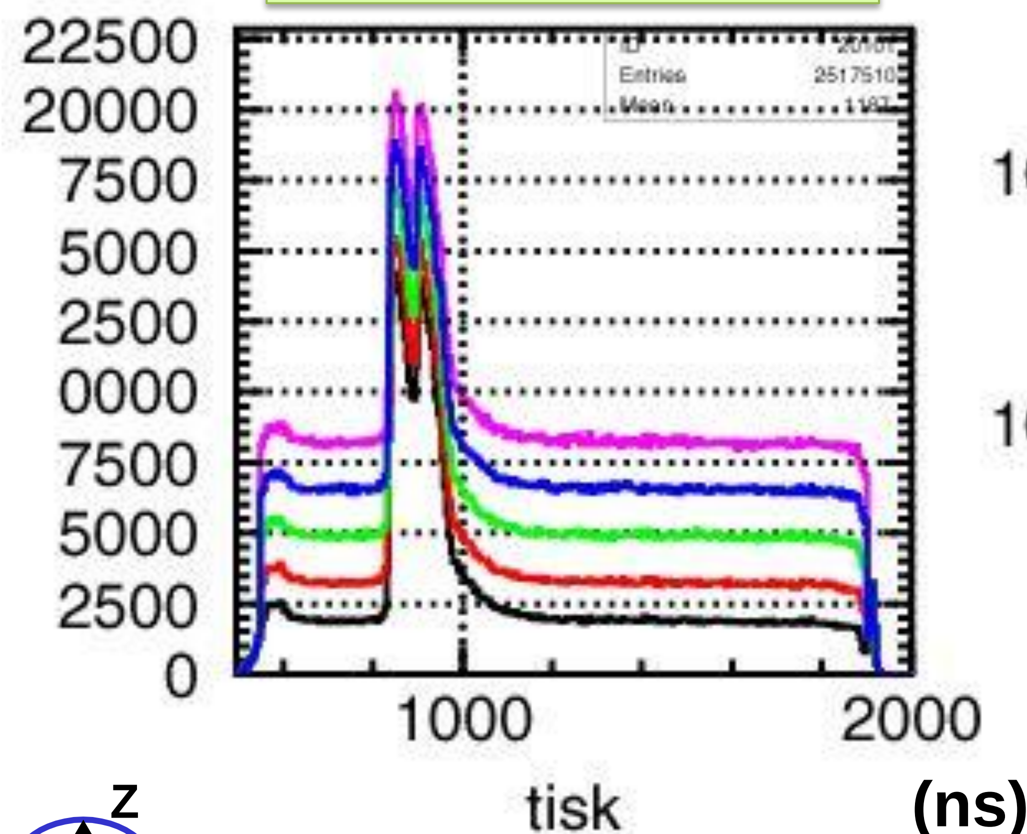




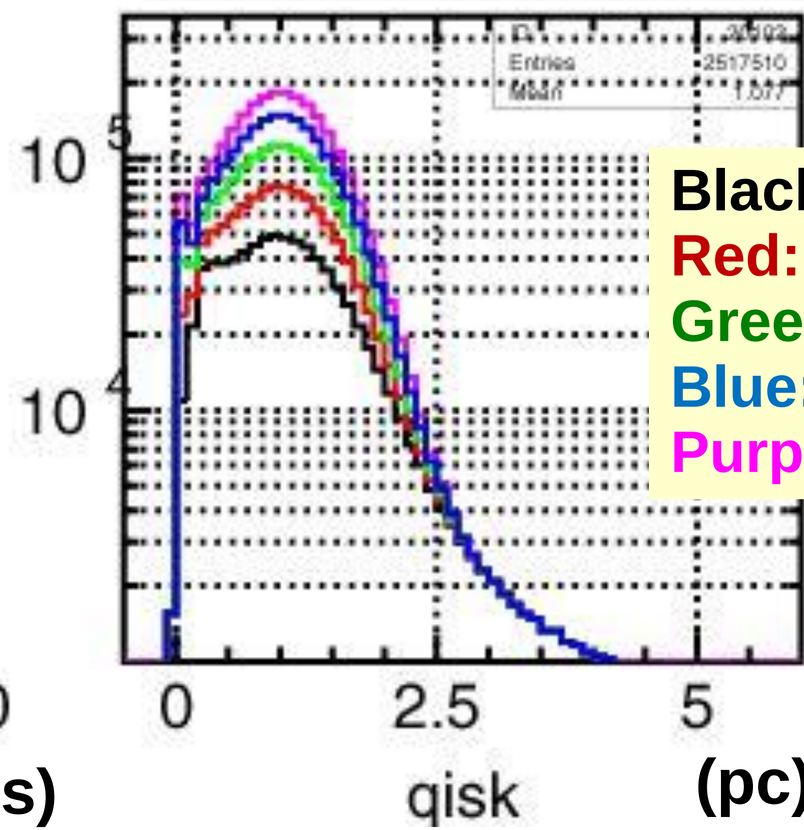
Effects on event reconstruction

- Dark rate hits in SK-I data are artificially increased.
  - SK-I observed dark rate: ~3.4kHz

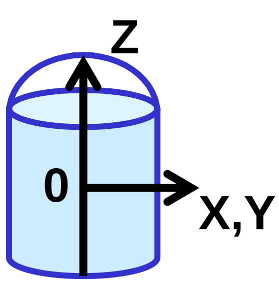
Time of each hit-PMT



Charge of each hit-PMT



Black: original
Red: ~1.5
Green: ~2.0
Blue: ~2.5
Purple: ~3.0



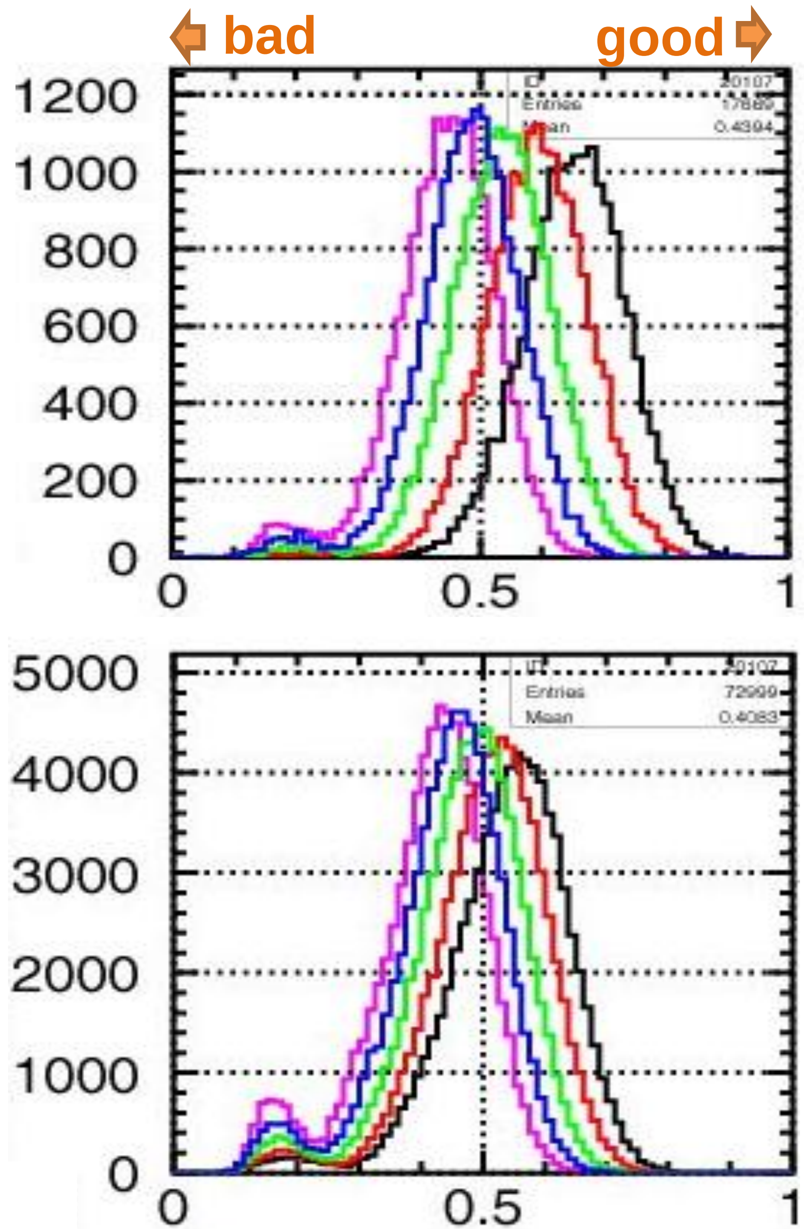
SK-I LINAC data (5 MeV, X=-12m Z=0m)

Vertex (timing) goodness

Signal:
SK-I LINAC
5MeV
X=-12m Z=0m

Background:
SK-I SLE
triggered
events

(without Intelligent Trigger filtering)



Timing goodness (from Bonsai fit)

Poor goodness separation under high dark rate

Black: original
Red: ~1.5
Green: ~2.0
Blue: ~2.5
Purple: ~3.0

Event quality parameters in SK-II

SOLAR NEUTRINO MEASUREMENTS IN SUPER- ... PHYSICAL REVIEW D **78**, 032002 (2008)

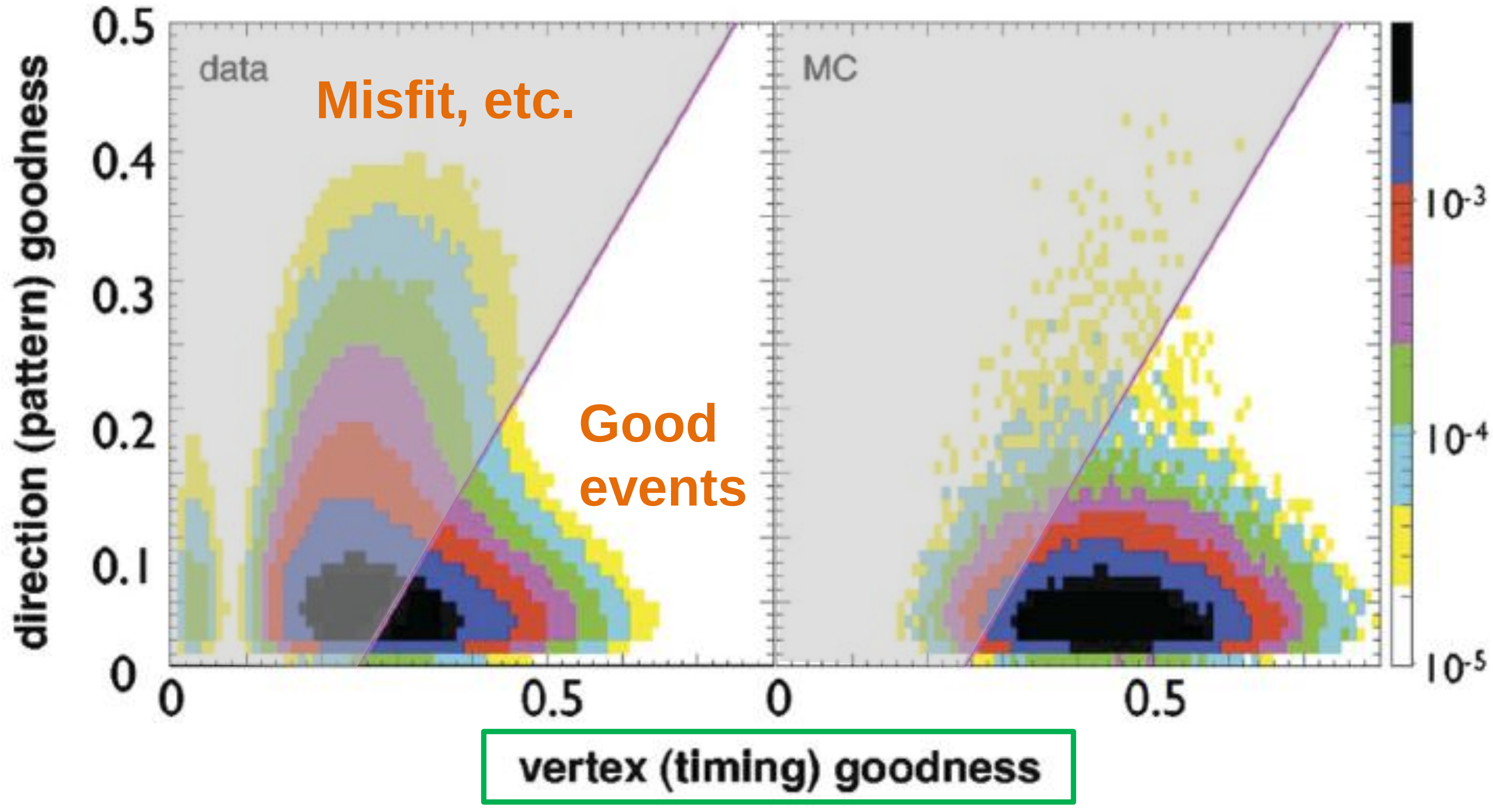


FIG. 9 (color). PMT timing and hit pattern cut. Data (left) show an excess of misreconstructed and non-Chrerenkov events to the upper-left of the diagonal cut line. Approximately 78% (8%) of data (MC) events between 7.0–7.5 MeV are rejected by the cut. The color scale is to show the relative (normalized) number of events.

- **High dark rate will increase low-e background events**
  - **Need to estimate**

Summary

- Expected BG increase for solar neutrinos in HK is factor about 10 (comparing to SK-II) per unit volume with 80% signal efficiency, under a basic relic spallation cut.

  →Y. Koshio's study

- If we apply a similar cut which removes (almost) all the spallation events in 17.5-26MeV in SK, the signal efficiency in HK becomes 21~46%.

  →T. Yano's study

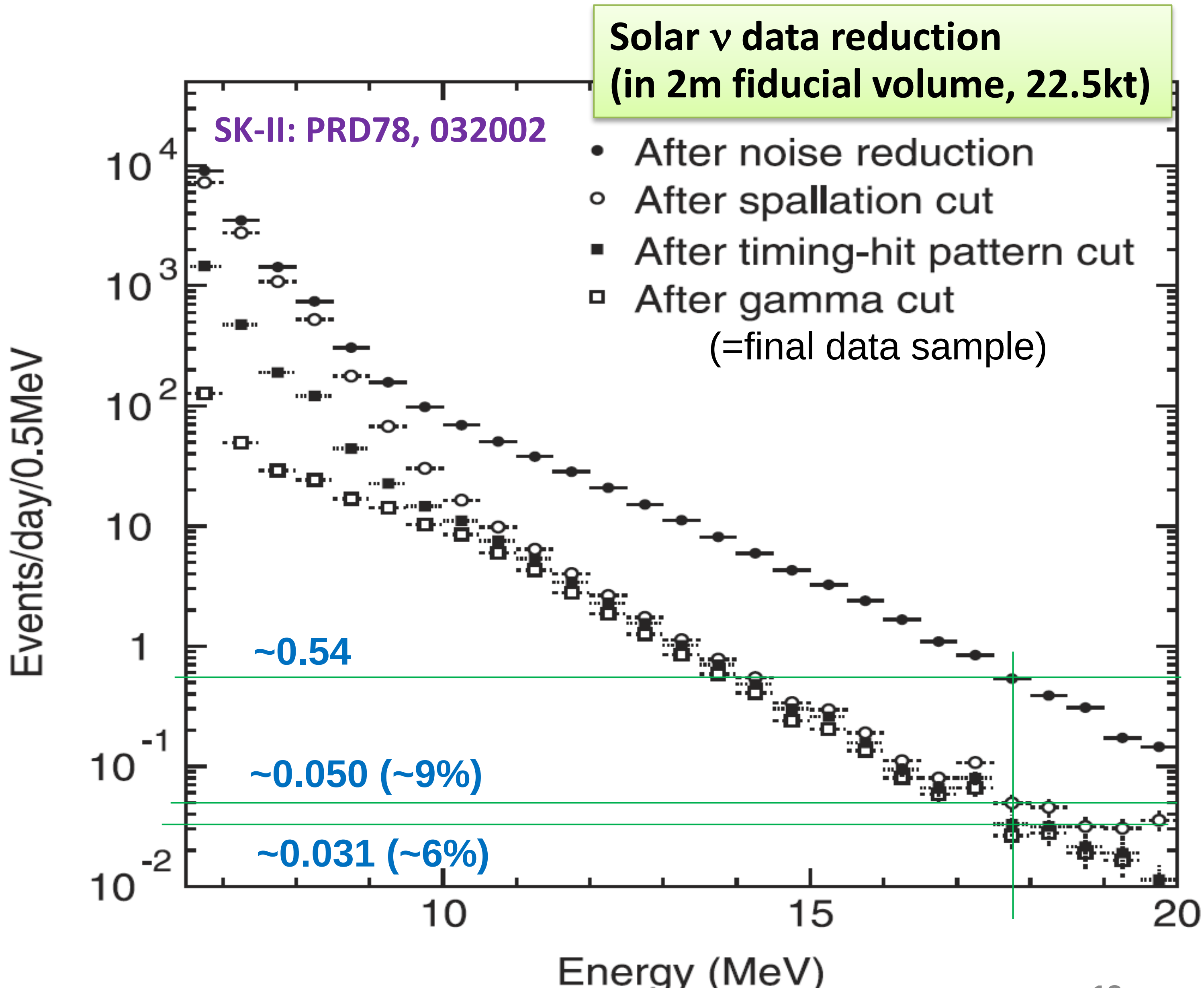
- High dark rate will degrade event quality parameters.

SUPPLEMENTS

Low-energy backgrounds in SK

Those events which reduced by the timing-hit pattern cut may not be spallation products.

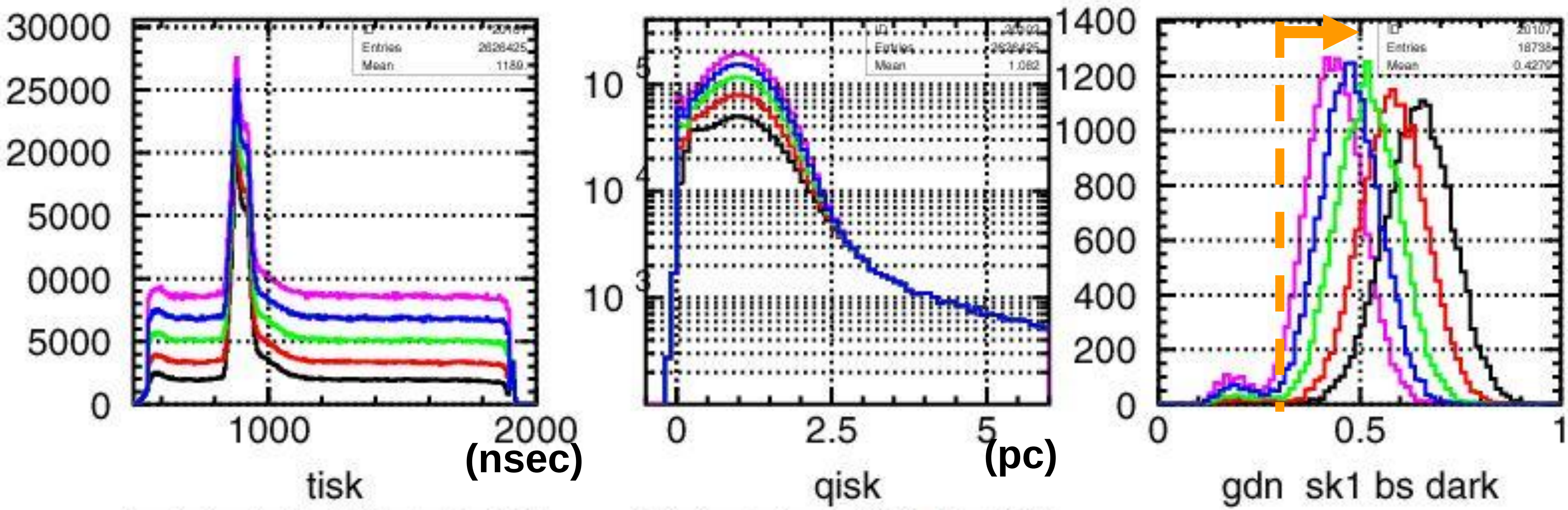
Remaining spallation products in SK-II in 17.5-18.0 MeV looks 6~9%

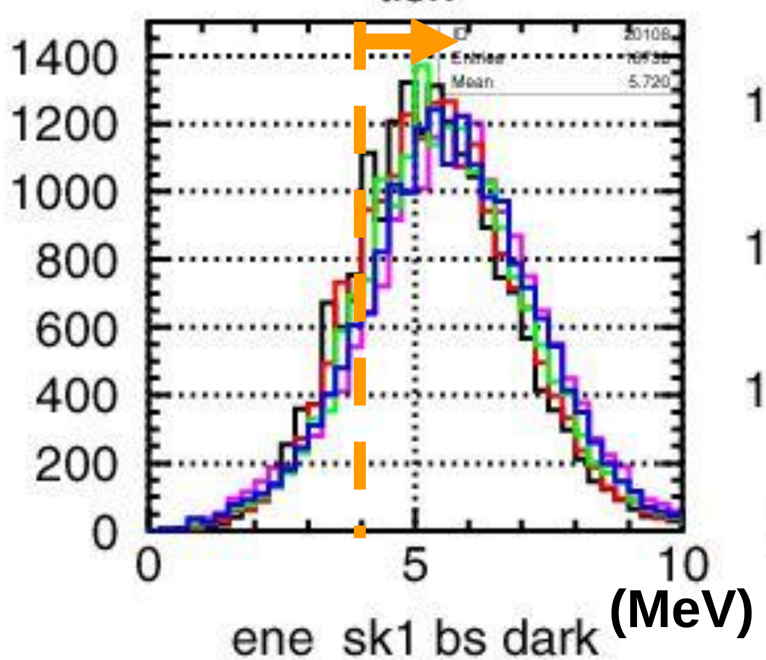


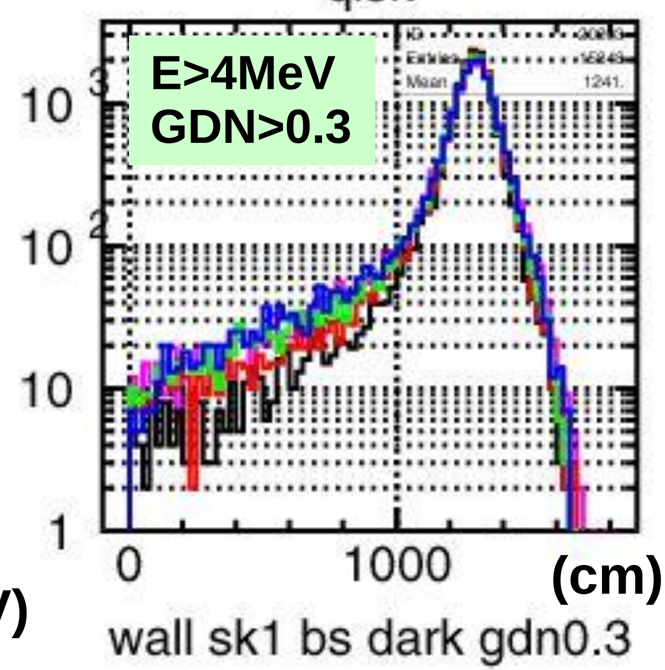
Possible effect of high dark rate in SK

- By increasing the dark rate artificially, event reconstruction quality were studied.
- Used data sample:
  - SK-I pre-scaled rejected events
  - SK-I LINAC data
- Applied factor: dark rate x 1.5~3.0
- Method:
  - Increase number of hit by Poisson
  - Generate uniform T and only low Q
  - Apply BONSAI fit

High dark rate study:1



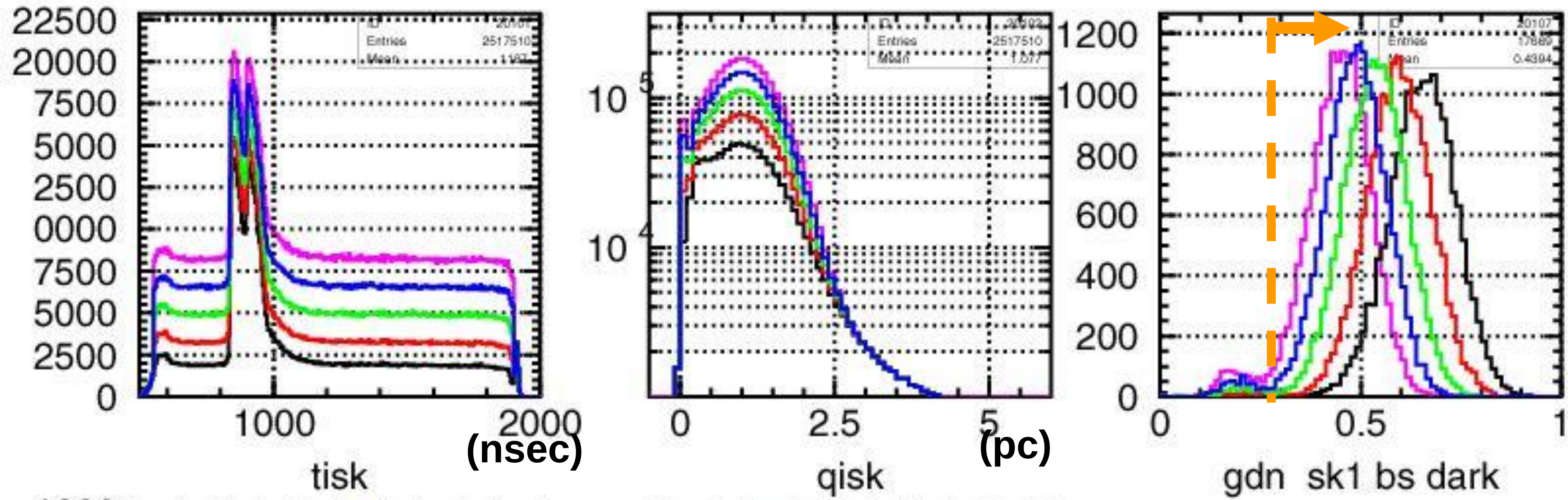


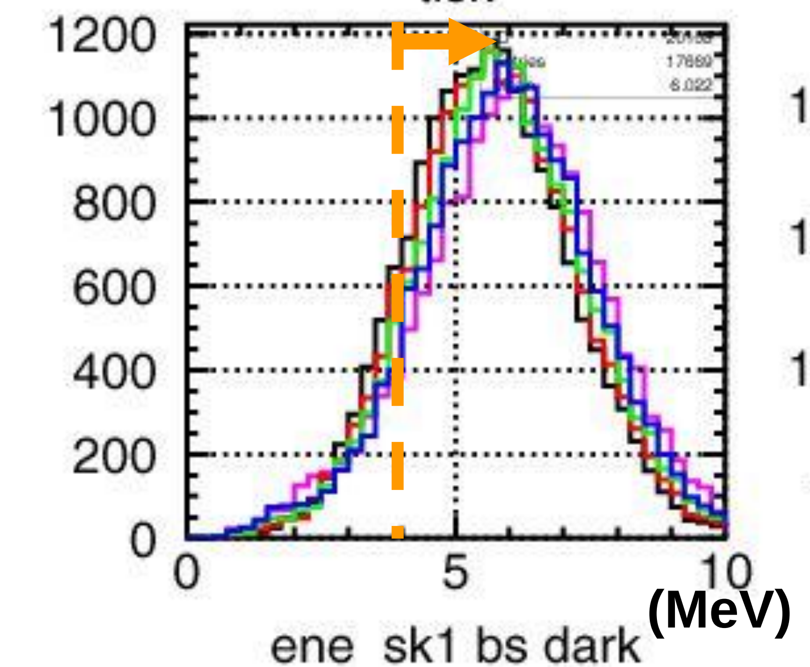


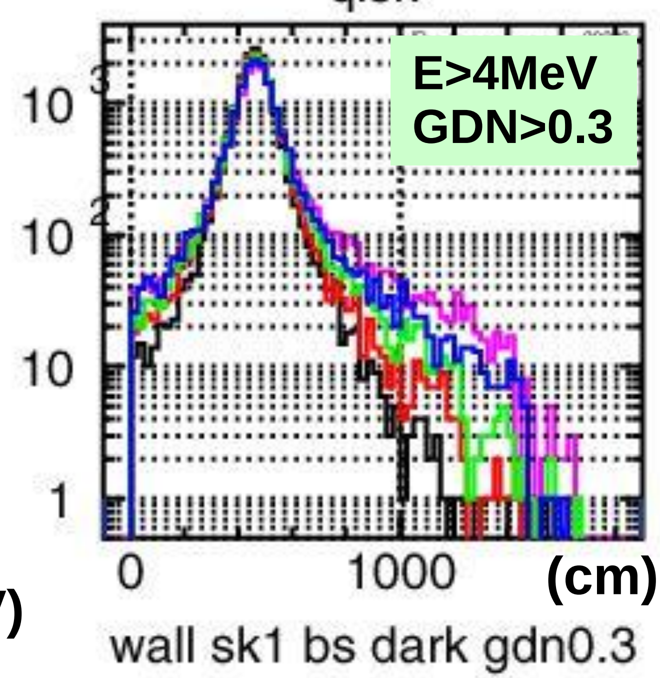
SK-I LINAC
X=-4m Z=0m

Black: original
Red: ~1.5
Green: ~2.0
Blue: ~2.5
Purple: ~3.0

High dark rate study:2



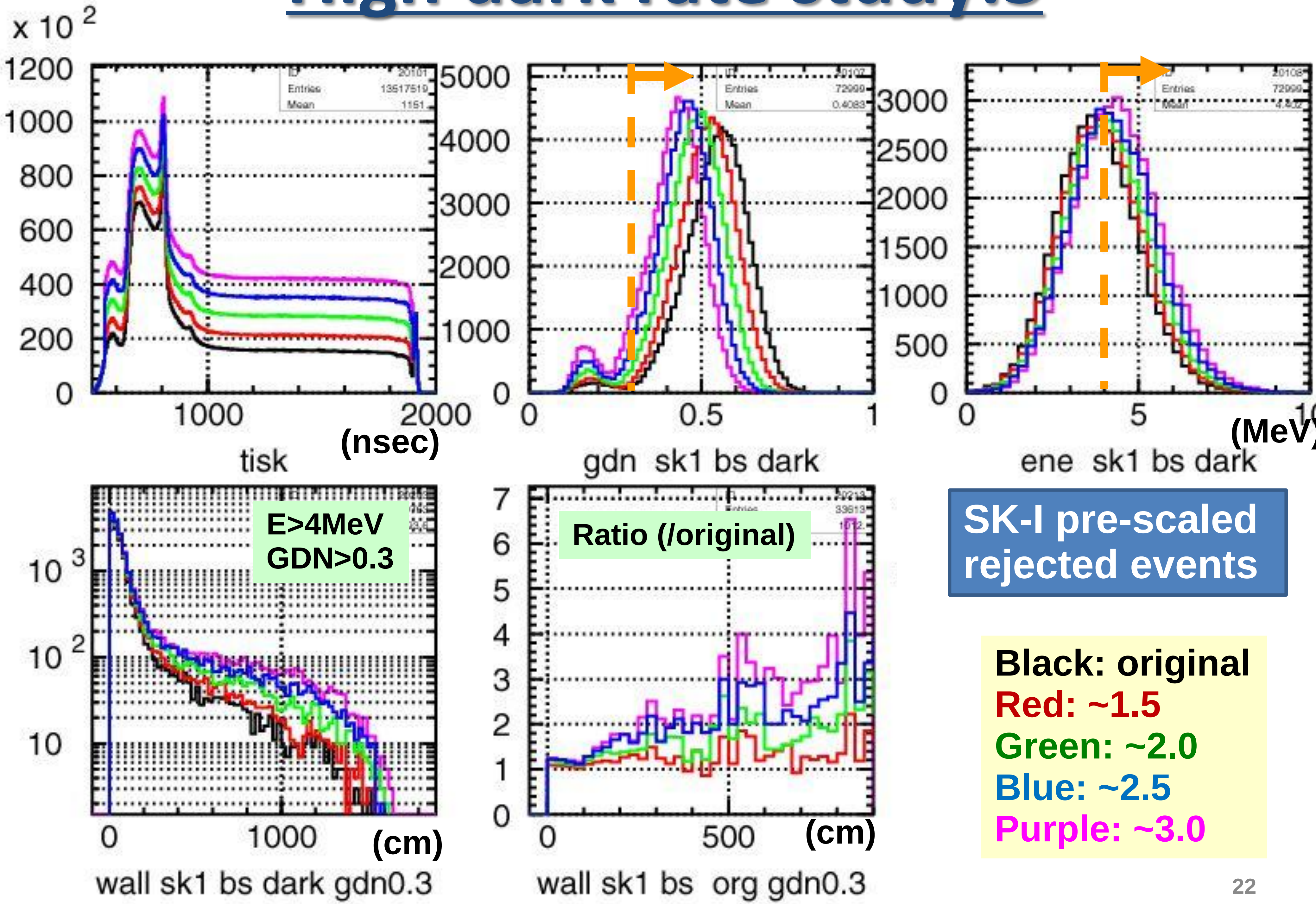




SK-I LINAC
X=-12m Z=0m

Black: original
Red: ~1.5
Green: ~2.0
Blue: ~2.5
Purple: ~3.0

High dark rate study:3

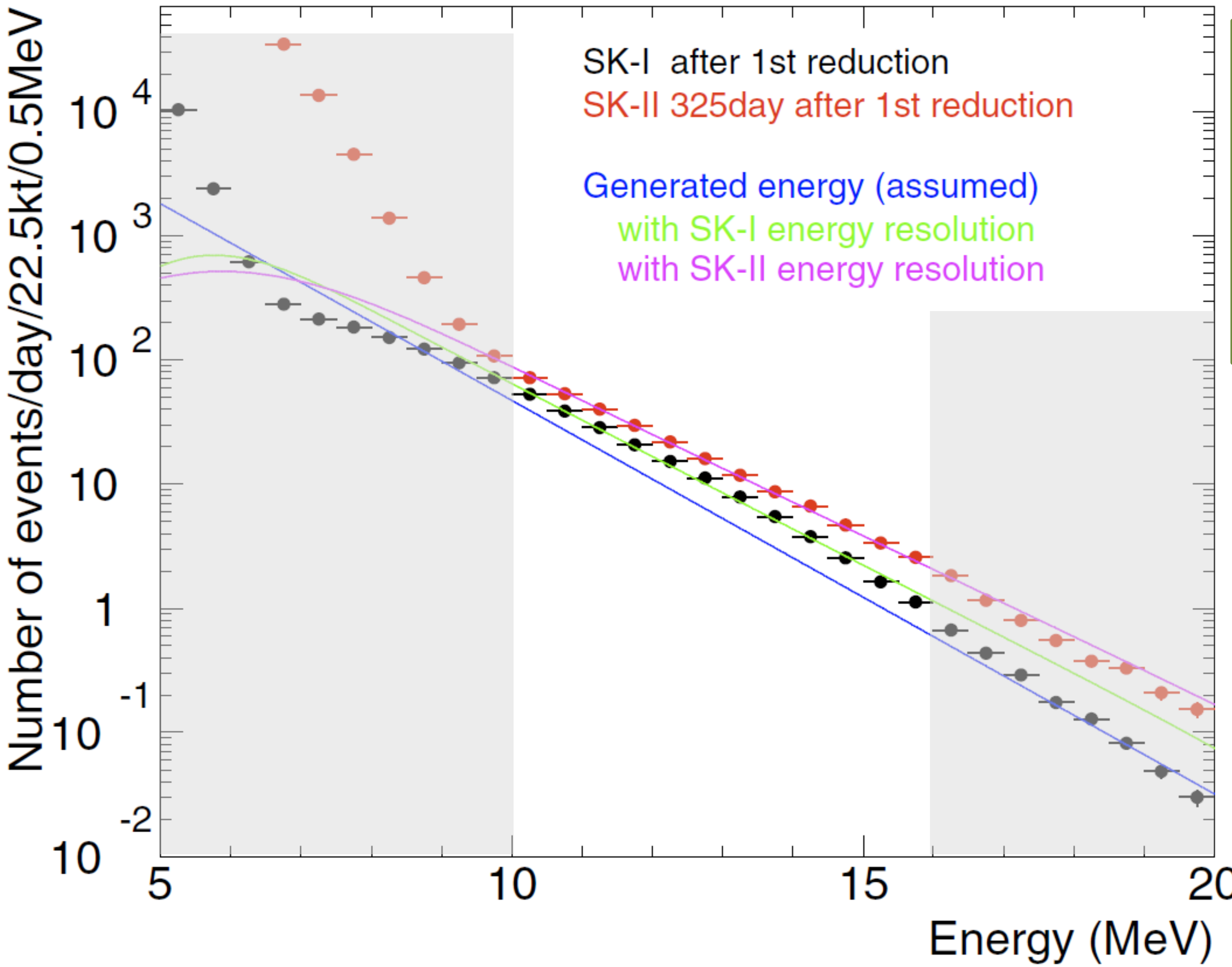


SK-I pre-scaled rejected events

Black: original
Red: ~1.5
Green: ~2.0
Blue: ~2.5
Purple: ~3.0

After 1st reduction

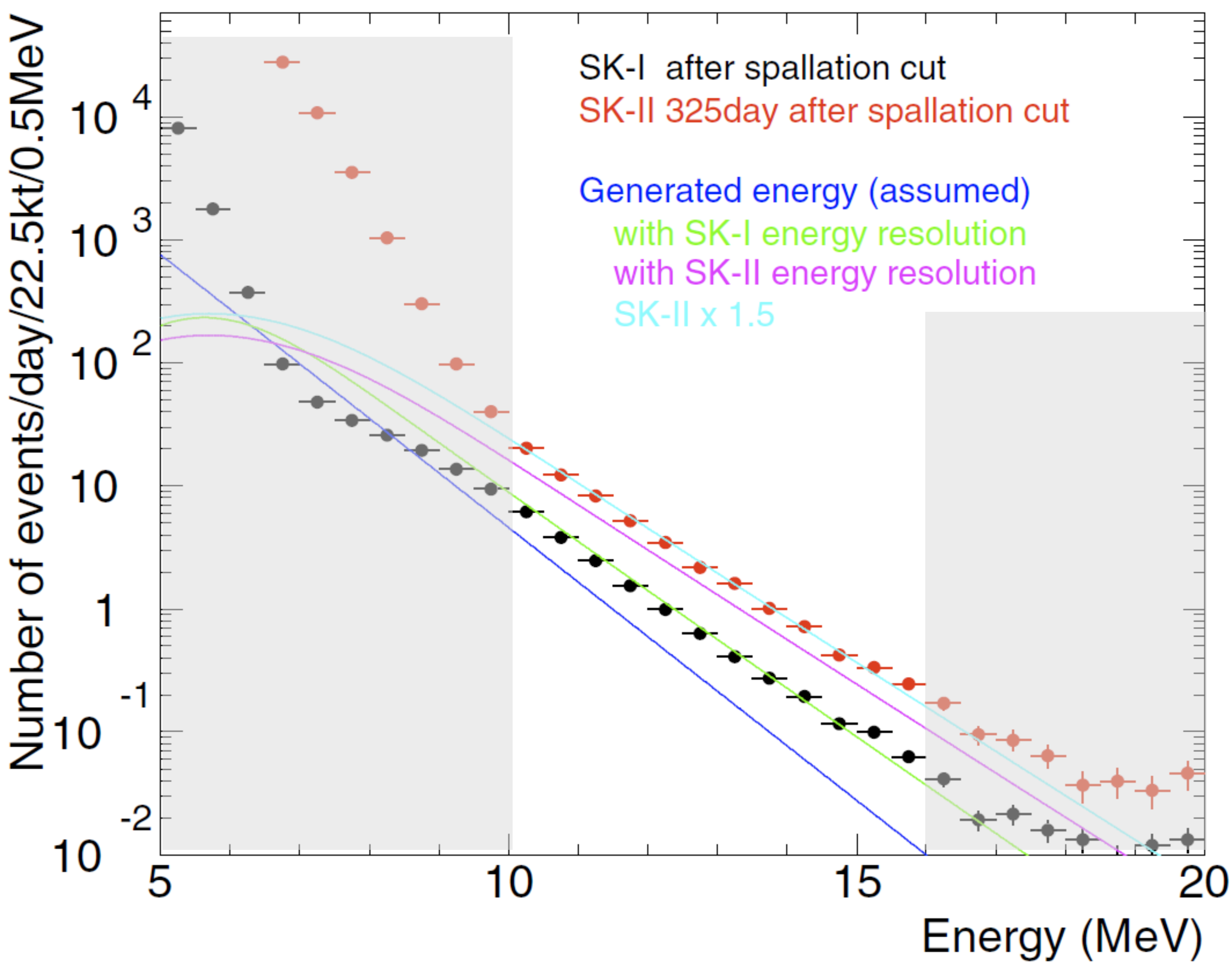
- Partial SK-II data were used in this study
- Cut criteria of SK-II may not be final.



The difference in 10-16MeV region could be explained by the energy resolution difference.

(Trigger efficiency < 8 MeV is not corrected)

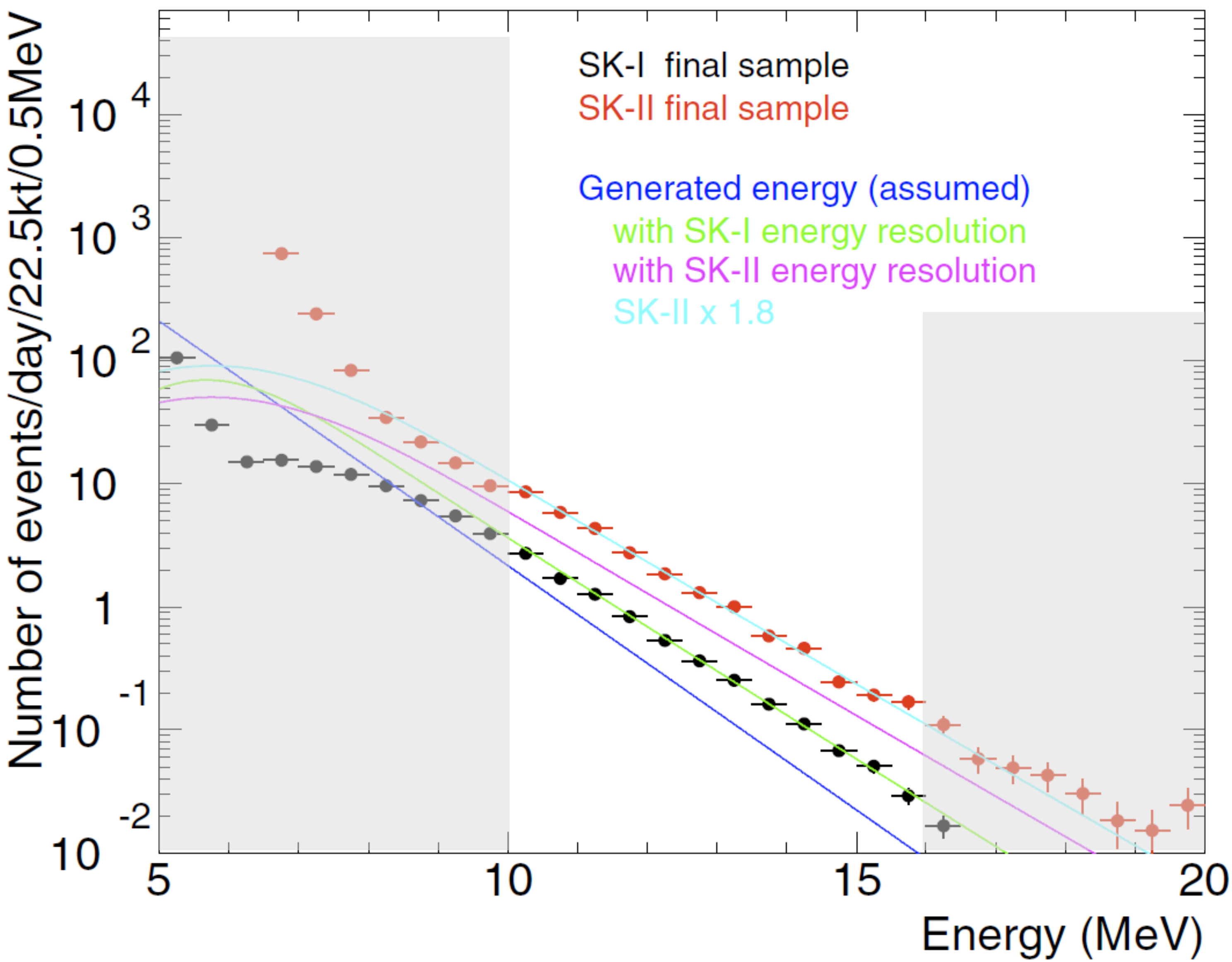
After (solar) spallation cut



Factor 1.5 larger than the energy resolution difference.

It might be due to the low-energy vertex resolution difference
(not confirmed yet)

Final sample



Factor 1.8 larger than the energy resolution difference.