

Search for GRB neutrinos at SK (and HK)

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**SYNERGIES AT NEW FRONTIERS AT
GAMMA-RAYS, NEUTRINOS AND GRAVITATIONAL WAVES**

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Tokyo, Japan

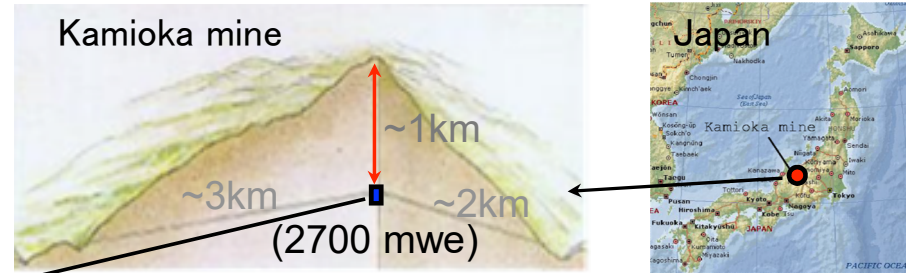
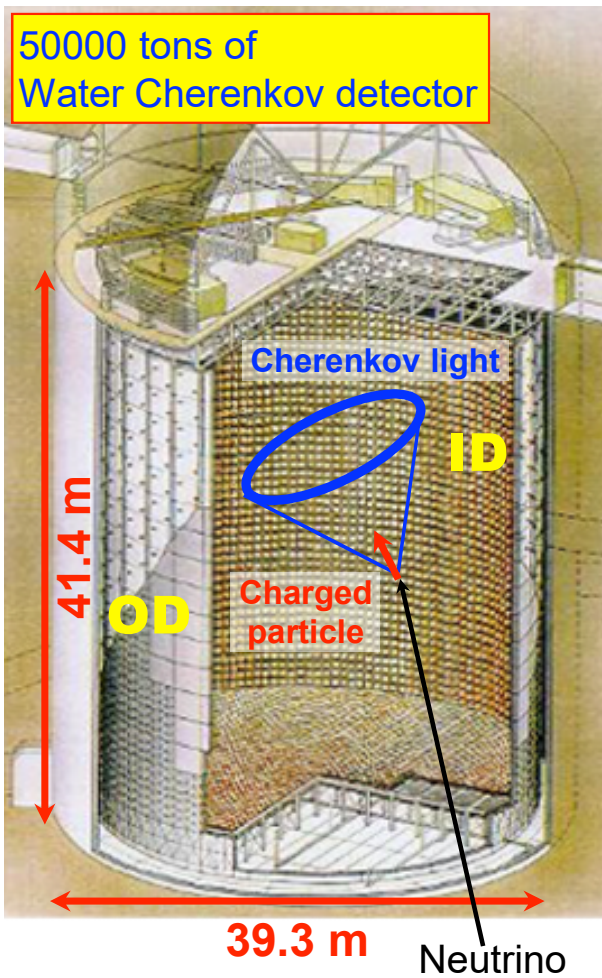
24 -25 MARCH 2022



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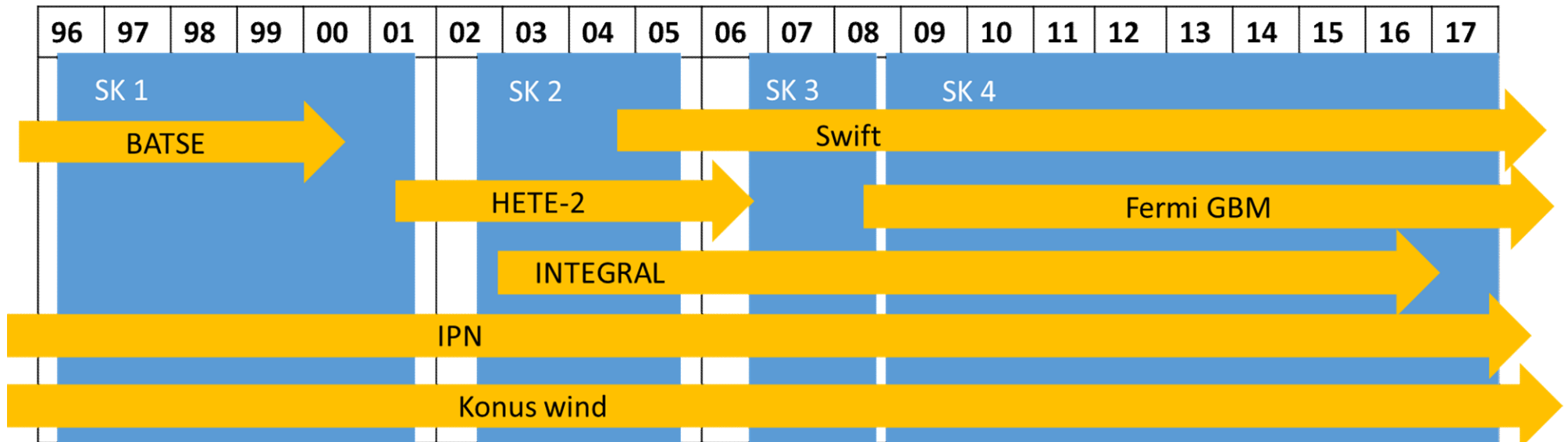
Super-Kamiokande detector



Phase	Period	Fiducial vol. (kton)	# of PMTs	Energy thr.(MeV)
SK-I	1996.4 ~ 2001.7	22.5	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10		5182 (20%)	6.5
SK-III	2006.7 ~ 2008.8	22.5 (>5.5MeV) 13.3 (<5.5MeV)	11129 (40%) (coverage)	4.5
SK-IV	2008.9 ~2018.6	22.5 (>5.5MeV) 16.5 (4.5<E<5.5) 8.9 (<4.5MeV)		3.5 (Kin. energy)

GRB observations and SK operation

- More and faster information from satellite observations
 - Help (under)ground based follow up observations
 - Include : host galaxy, afterglow light curve
 - We can perform more detailed analysis
fluence limit for long GRBs and short GRBs
- Gamma-Ray Candidate Network (GCN) is available to get such information



GRB data base

- GCN database prepared by ICECUBE group
→ GRB web (all event, 2008-)
(Thanks to M.Tanka san for his advice)
- Analys period : 2008/12/7-2017/3/31
 - Total 2208 GRB in SK physics runs
 - Duration (t90) is available
2136 GRBs (323 short/ 1813 long)
 - GRB start/stop time are available
2194 GRBs

GRBweb by P. Coppi

Home ▾ Data ▾ Description Precursors Cor

Click [here](#) to view the full table (only the first 1000 lines are shown).
Click [here](#) to download this table as a text file.
Click [here](#) to access archived versions of the summary table.

Update: If the GRB_name is followed by an asterisk (*), then the GRB does not appear with a GCN-style name in the literature. These GCN-style names were hence auto-generated by GRBweb.

GRB_name	GRB_name_Fermi	TO	ra	dec	pos_error	T90	T90_error	T90_start	fluence	fluence_error	redshift	T100	GBM_located	mjd (TO)
		UTC	°_J2000	°_J2000	°_sigma	s	s	UTC	erg/cm ²	erg/cm ²		s		day
GRB220304*	GRB22030194	4:39:54.512	96.9100	-53.5400	—	19.9800	0.3620	4:39:56.304	4.3114e-05	6.9759e-08	—	21.7600	True	59538.19438093
GRB220319A	—	17:40:33	218.2242	61.2950	—	—	—	—	—	—	—	—	False	59657.73648306
GRB220317A	GRB220317534	12:48:23.496	171.9600	-11.2800	9.205360	14.3360	3.4820	12:48:23.496	6.7512e-07	2.2325e-08	—	14.3360	True	59555.53390528
GRB220316A*	GRB220316476	11:25:37.875	222.9100	41.9600	5.285599	48.1200	0.5720	11:25:38.451	6.4669e-06	2.6915e-08	—	48.7050	True	59654.47613281
GRB220315A	GRB220315101	2:25:56	236.0900	-76.8200	4.498885	0.7800	0.6680	2:25:56.619	4.1031e-07	2.1466e-08	—	1.3870	True	59553.10134259
GRB220314A*	GRB220314898	21:32:56.456	174.8400	1.1000	4.484832	30.4650	1.2800	21:32:56.436	7.2787e-06	7.3995e-08	—	30.4650	True	59652.89787542
GRB220311A	GRB220311690	16:33:10	157.9747	66.0819	—	10.4960	1.9500	16:33:12.257	1.2482e-06	4.3046e-08	—	12.7330	False	59649.68699907
GRB220310C	GRB220310933	22:23:48.355	289.9580	40.2093	—	16.3840	4.7000	22:23:48.355	7.1838e-07	6.0341e-08	—	16.3840	False	59648.85319855
GRB220310B	GRB220310122	2:55:07	63.8300	69.5800	4.155865	5.3760	0.4530	2:55:07.739	1.4584e-06	3.1142e-08	—	6.1150	True	59648.12160880
GRB220304A	—	0:57:57	149.7637	10.7631	—	—	—	—	—	—	—	—	False	59648.01616497

https://user-web.icecube.wisc.edu/~grbweb_public/Summary_table.html

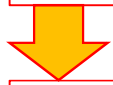
Analysis overview (MeV neutrino search)

Raw data (SK 4 period)



Apply calibration constant
Apply event reconstruction

First reduction



Cut noise events

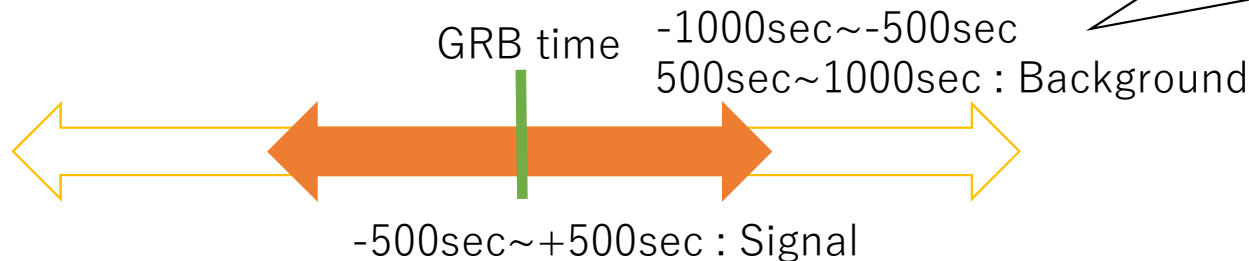
Second reduction



Cut physics background

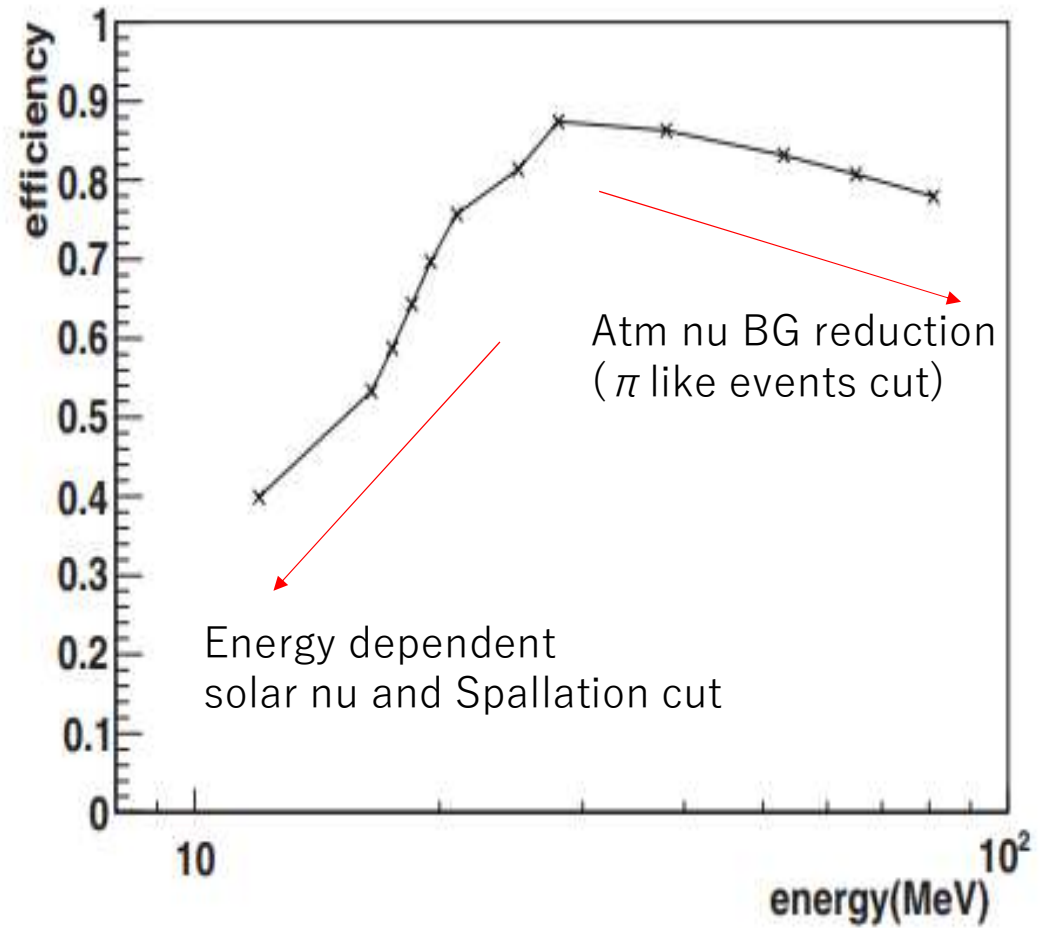
Select events around GRB

- For individual GRB
 - Fixed time window
 - + -500sec window
 - Variable time window
 - Use GRB start/stop time of the database
- Stacked analysis
 - Sum up all events around all GRBs
 - Check statistical excess from background



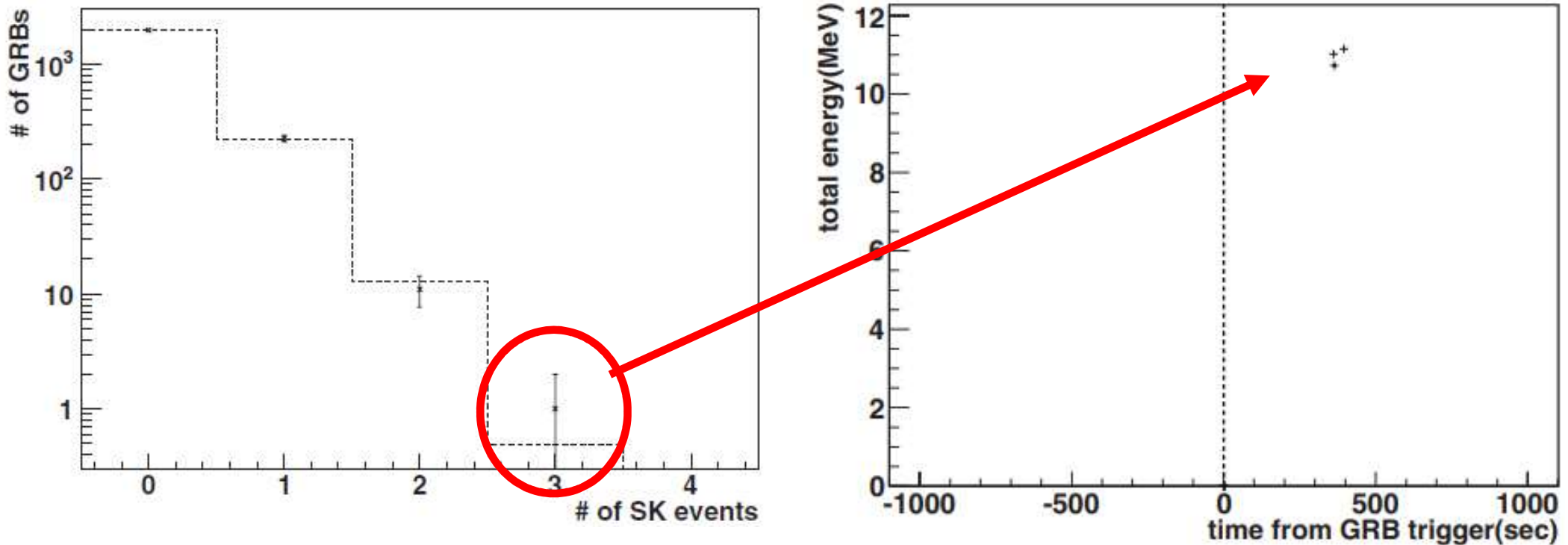
Summary of reduction

- First reductions
 - FV cut and other noise cuts
 - ~70% efficiency
- Second reductions
 - Solar nu BG (~ 20MeV)
 - Cut solar direction
 - Spallation BG (~ 20MeV)
 - Check correlation with all muons within 30sec
 - Atmospheric nu BG (higher energy)
 - Pion / muon like events
 - Hit pattern
 - Events with sub events
 - Hit pattern and hit timing



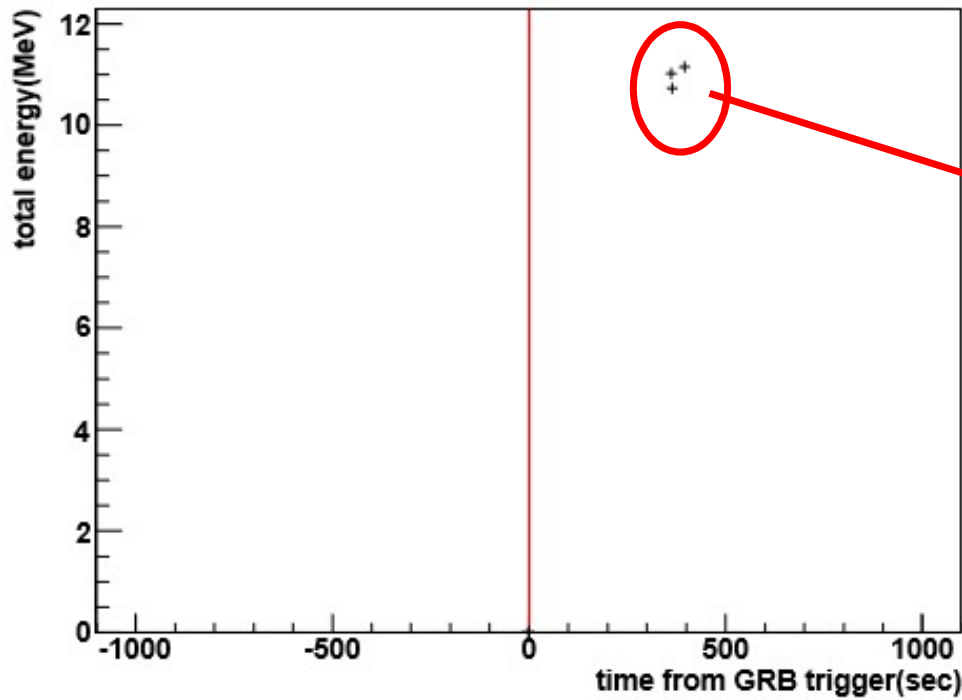
Fixed time window analysis

- Check ± 500 sec around individual GRB

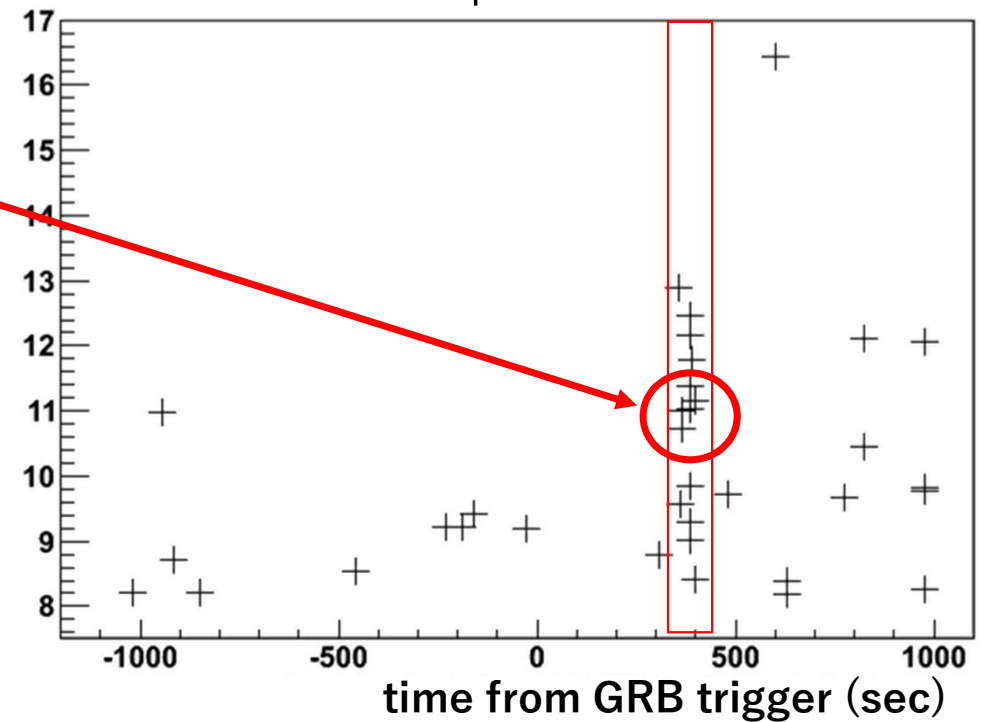


Background rate is obtained from the sideband (± 1000 sec) : 0.114 event/1000sec
Number of observed SK events agree with the Poisson distribution of BG rate

3 events due to spallation products...



Events before spallation cut

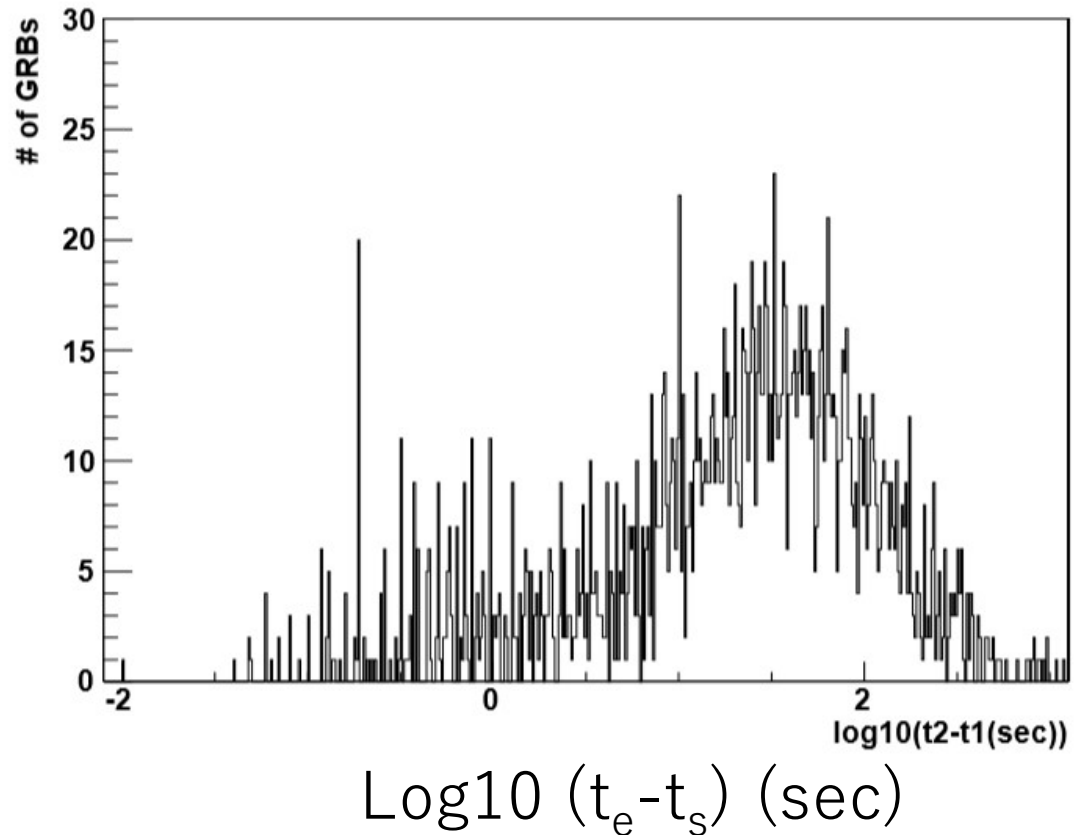


We also confirmed that positional correlation with the parent muons

Variable timing window analysis

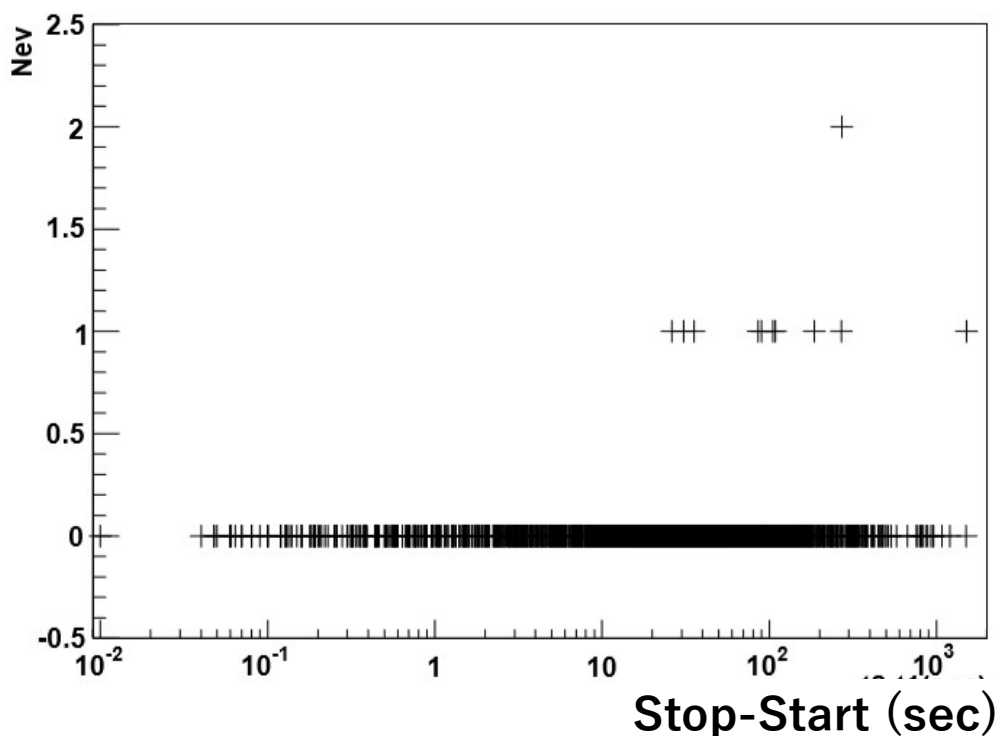
The length of search time window is different for each GRBs

- GRB's start time and stop time is available
 - 2194 GRBs
- Start (t_s) and stop (t_e) time:
 - $O(0.1\text{sec})$ to $O(1000\text{ sec})$
 - Let' search events within the time window

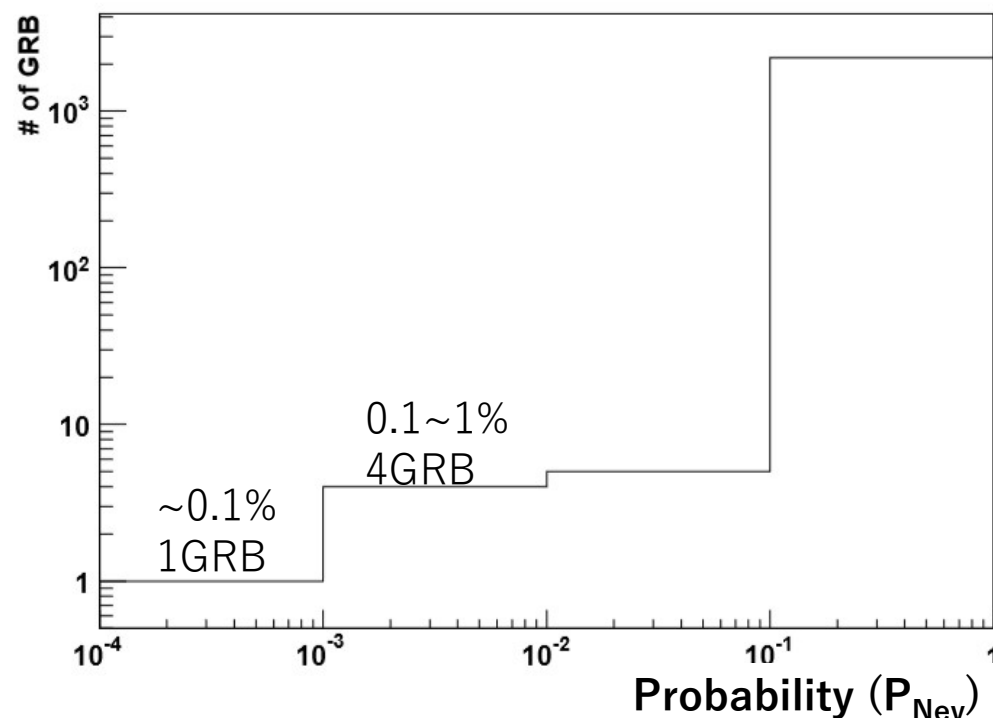


Events in the individual time window

Number of candidate events (N_{ev}) for each GRB



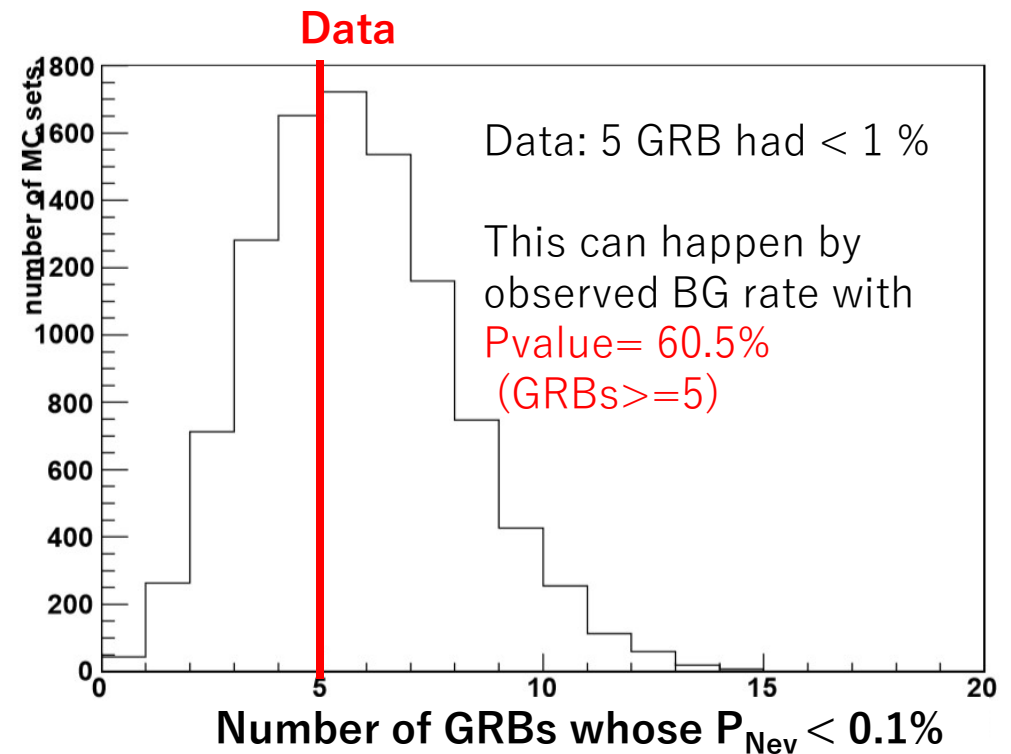
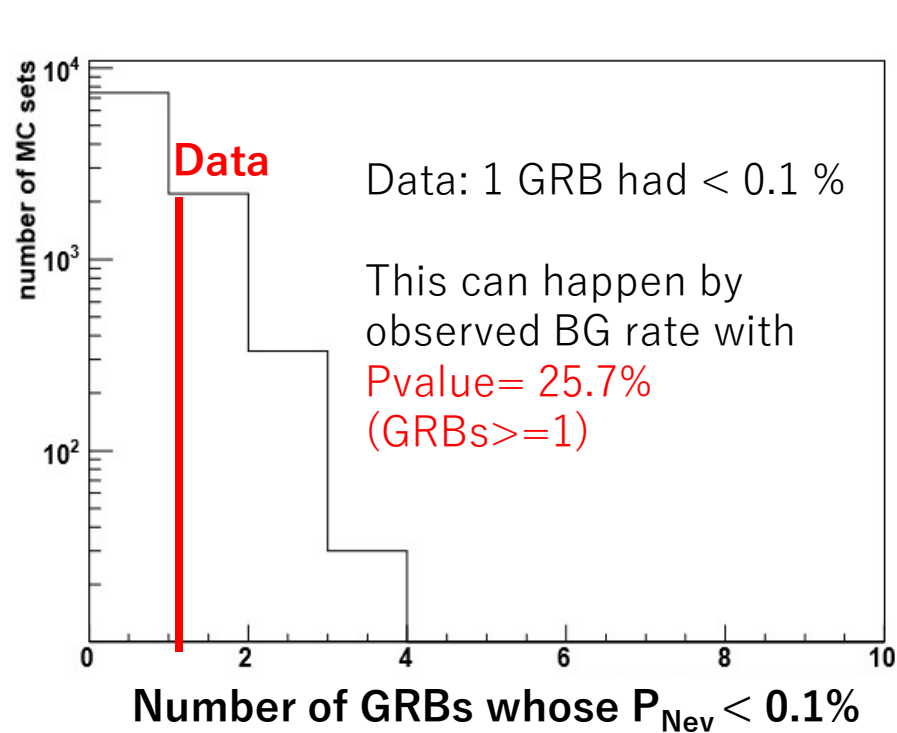
Distribution of probability ($P_{N_{ev}}$)
to observe N_{ev} for each GRB



※ $P_{N_{ev}}$: N_{ev} events to be observed in $(t_e - t_s)$ sec with a Poisson distribution of the average background rate of 0.114 events per 1000 s.

Statistical test with toy MC

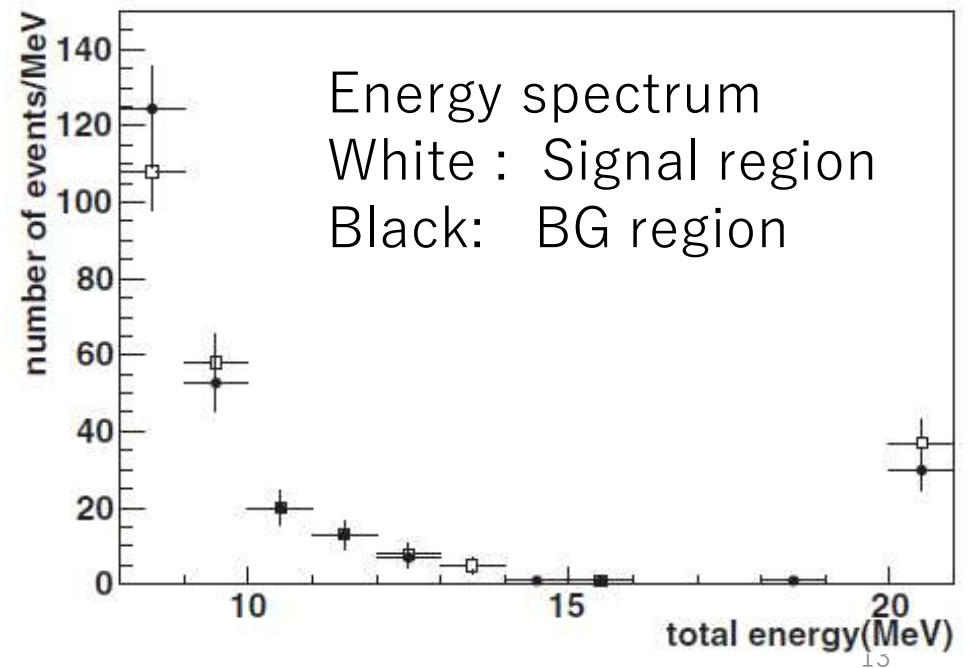
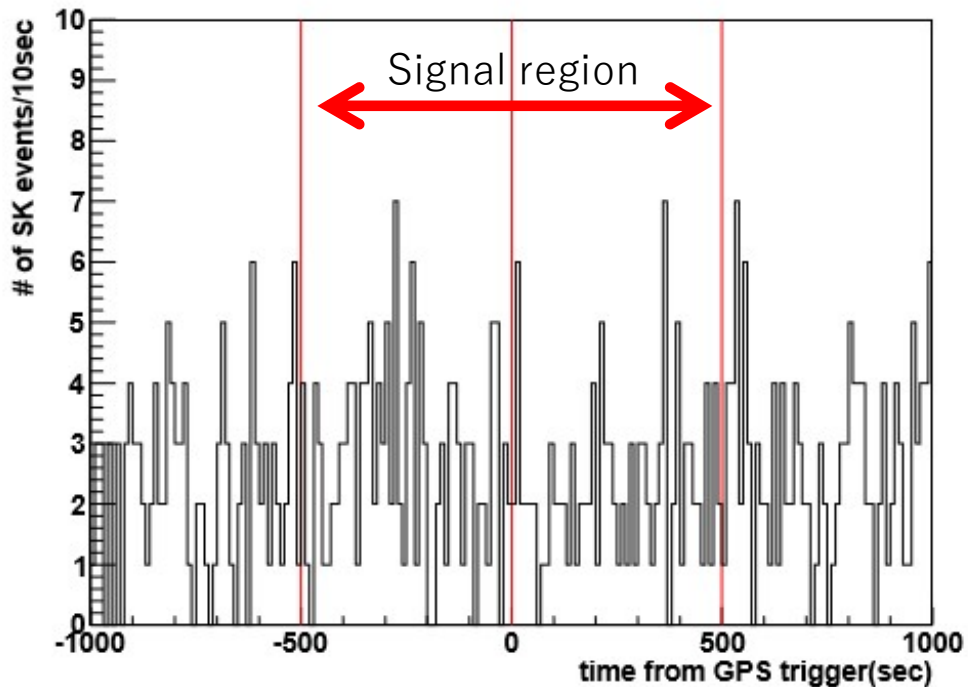
- From the observed BG rate, we have simulated 10000 sets of 2194 GRBs (with real $t_e - t_s$) and checked P_{Nev} as it's done for data



Therefore, the result (previous page) is not statistically significant. ¹²

Stacked data analysis

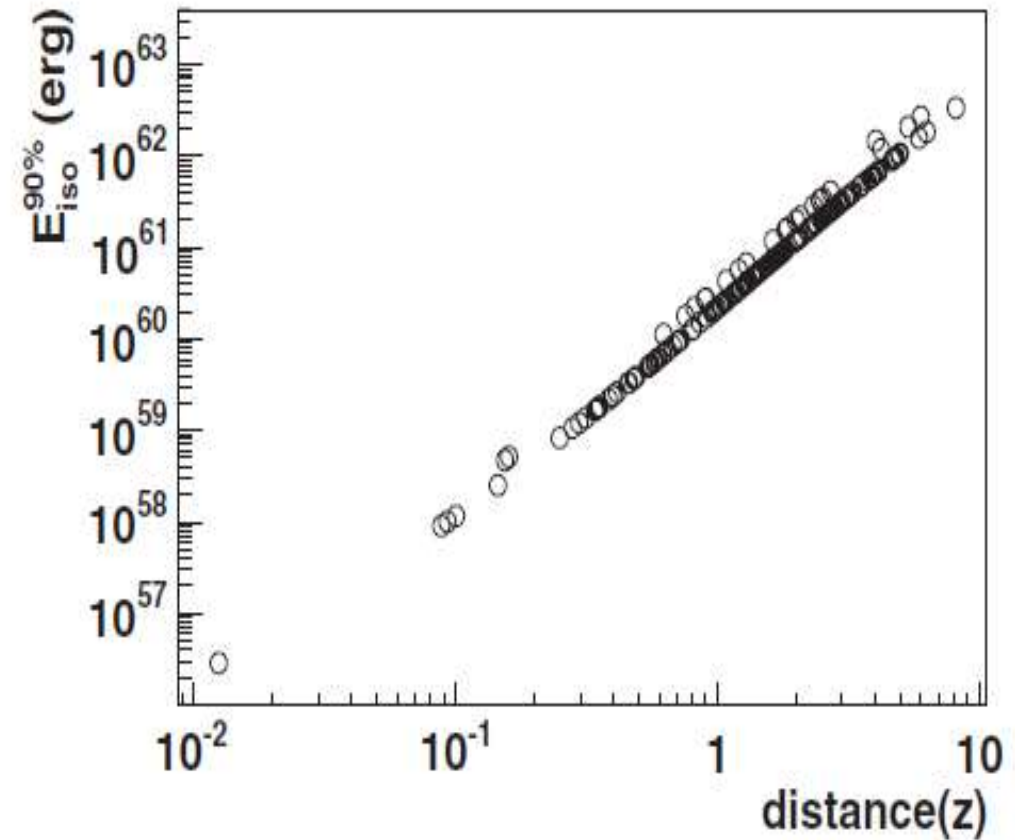
- Sum neutrino candidate events for all 2208 GRB
 - Signal window ± 500 sec of GRB timing
 - Background window ± 1000 sec (500 sec out side of signal window)



Fluence upper limit

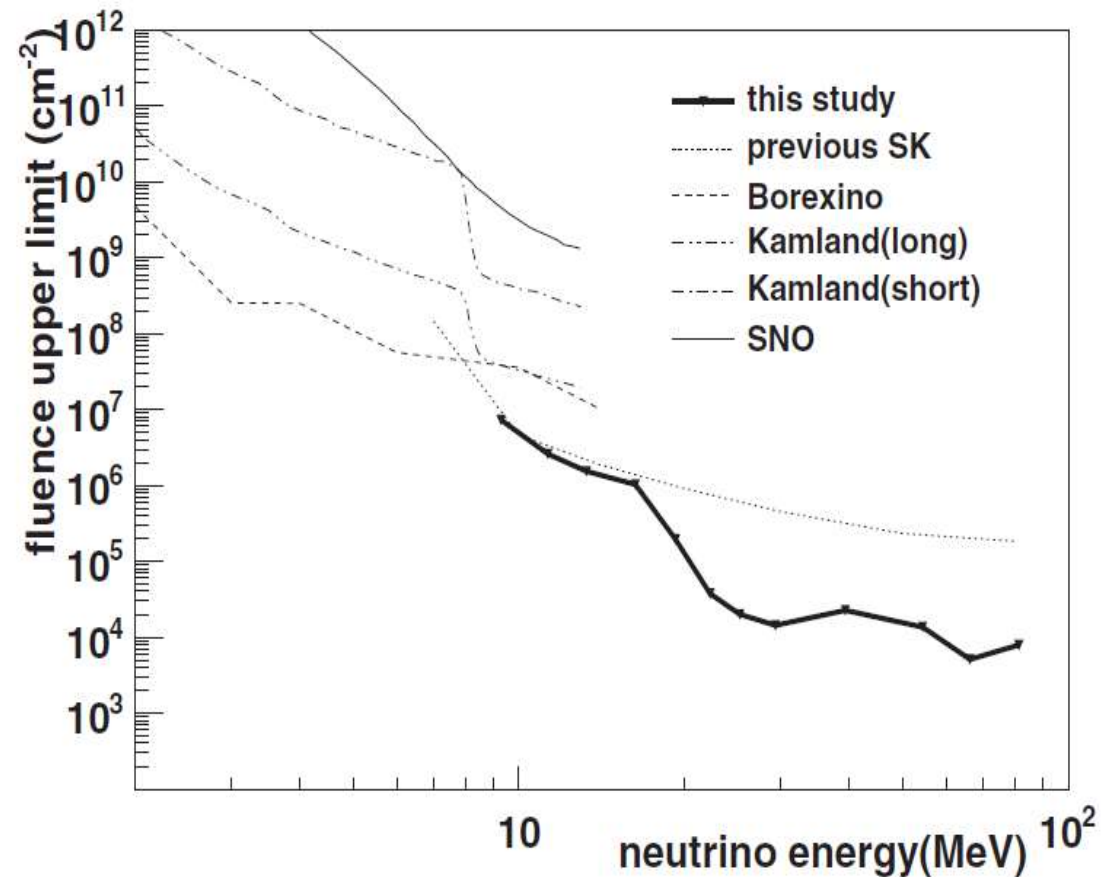
Total fluence $< 1.12 \times 10^8 \text{ cm}^{-2}$ / 2208 GRBs
= **$5.07 \times 10^4 \text{ cm}^{-2}$ / GRB**

- 8 MeV to 100 MeV
- Assuming a flat spectrum at GRB
- For 189 GRBs, distance is available in the database.
 - Limits on the total energy carried away from the source by neutrinos can be calculated.
 - Assuming neutrino emission at the source is isotropic



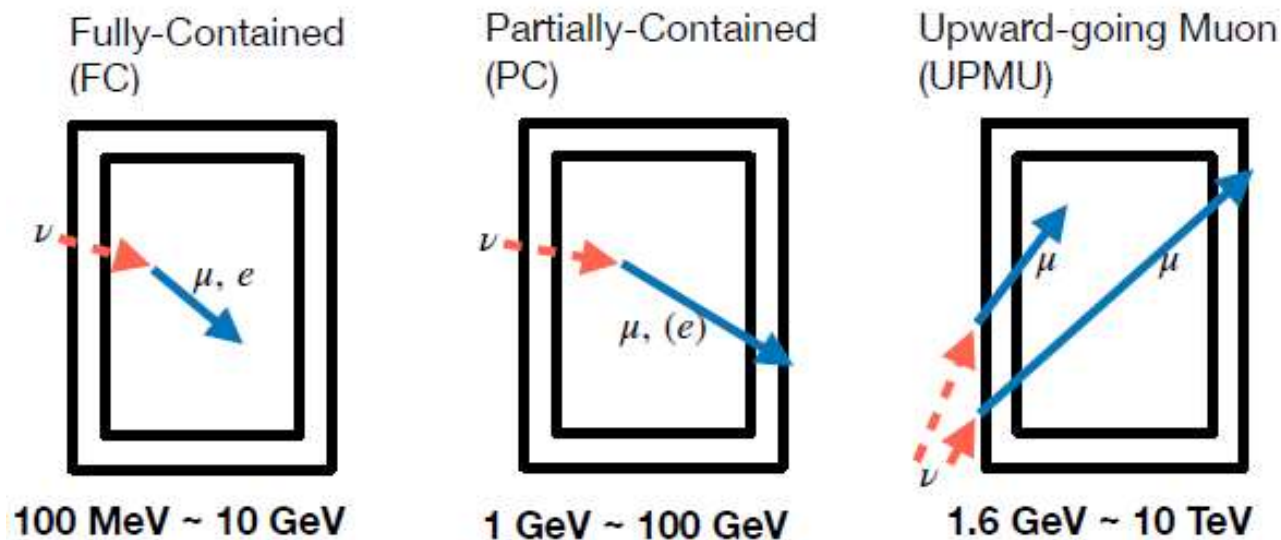
Fluence vs. energy

- Fluence limit per GRB is calculated as a function of energy.
- For each energy point(E), the number of candidate events with energy $\pm 3\sigma_E$ around the point is counted.
- Limits for short and long GRBs are also calculated in the paper.



Higher energy GRB neutrino search

- Search of 100 MeV – 10 TeV using data from SK1-4 (more than 20year).
- Use GRBweb
 - 3864 GRBs found during the period
- The correlation between ν direction and event direction is strong.
 - Look for events within 15 degree to GRB direction
- We have 3 categories depending on neutrino energy



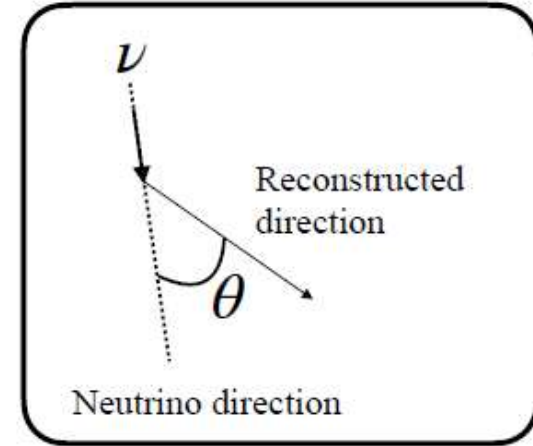
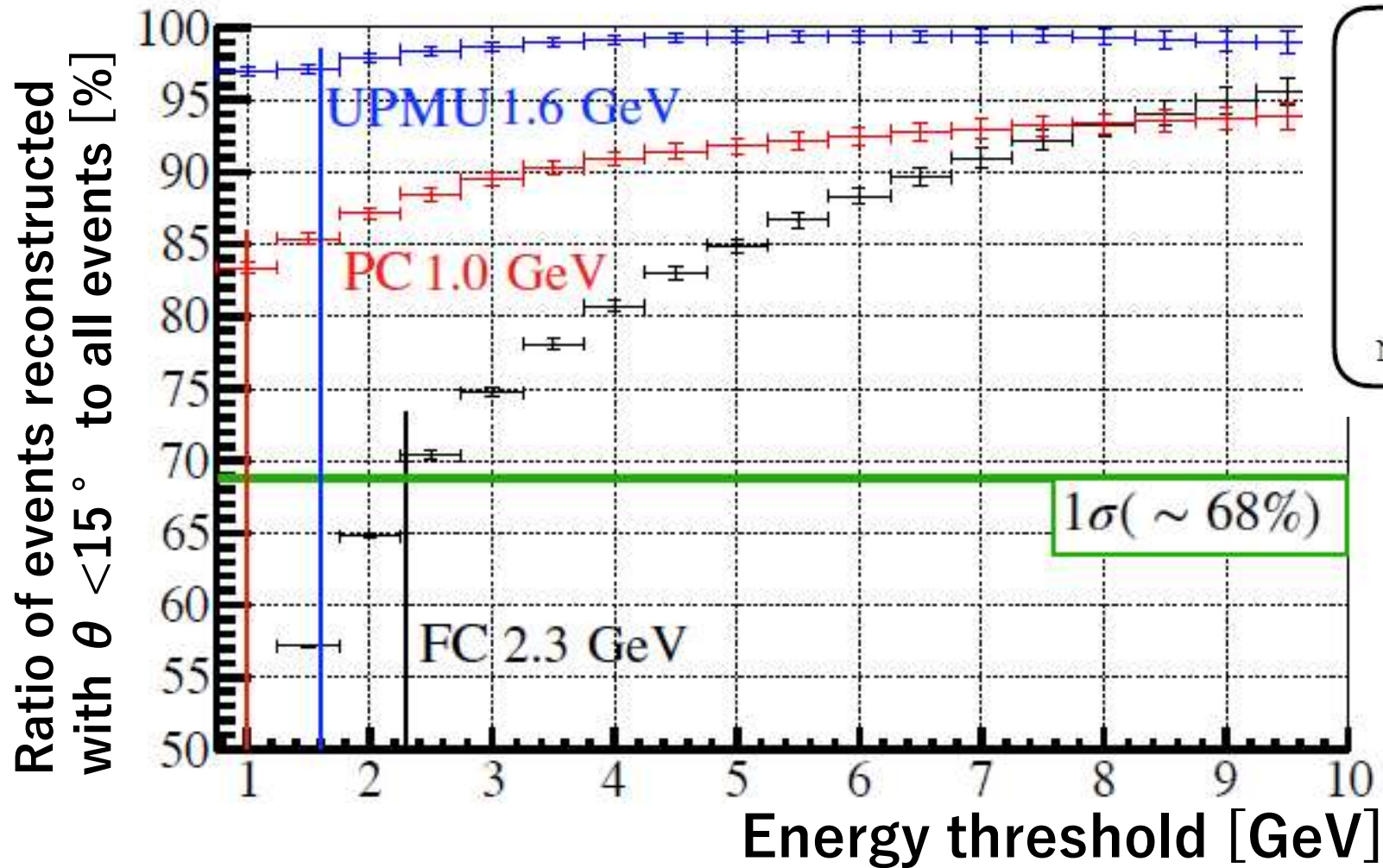
Atm. nu background estimation

At high energy, atmospheric neutrino BG is dominant BG source.

Data and MC shows good agreement

Event rate [$\times 10^{-5}/\text{sec}$]	Data	MC
FC	9.44 ± 0.05	9.43
PC	0.72 ± 0.02	0.74
UPMU	1.60 ± 0.04	1.57

Energy threshold for each category



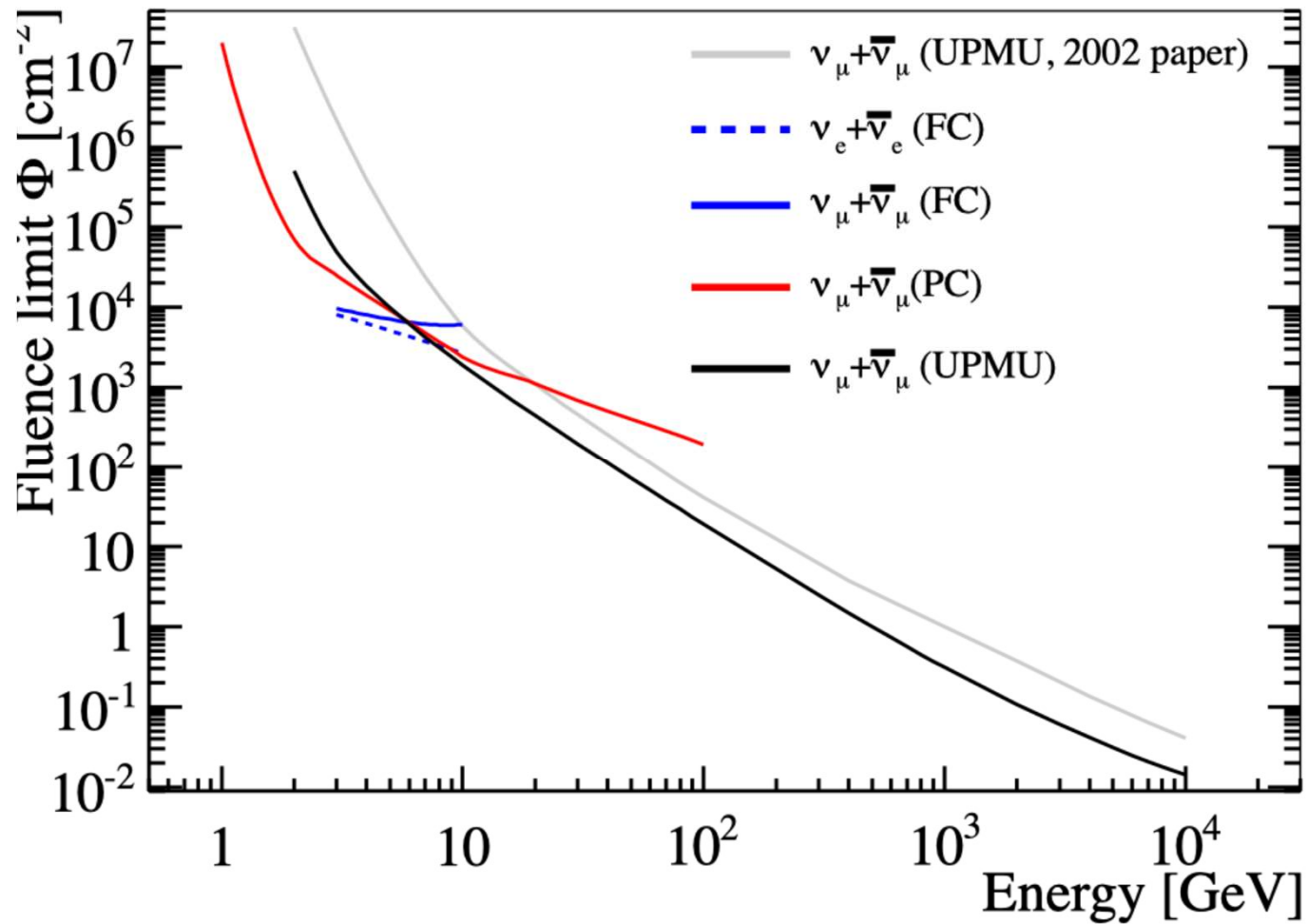
Results:

- Count number of candidates with
 - ± 500 sec of GRB time
 - Difference between the reconstructed direction and GRB direction $< 15^\circ$
 - (Only for UPMU) z direction of GRB < 0
- No significance observed

	# of GRBs	Data	Expected BG
FC	3737	2 ± 1.4	0.77
PC	3737	0	0.48
UPMU	1737	1 ± 1.0	0.76

90% C.L. fluence upper limit

Preliminary

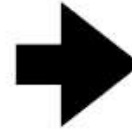


Assuming flat spectrum from GRB

90% C.L. energy flux upper limit with E^{-2} (or E^{-1}) spectrum

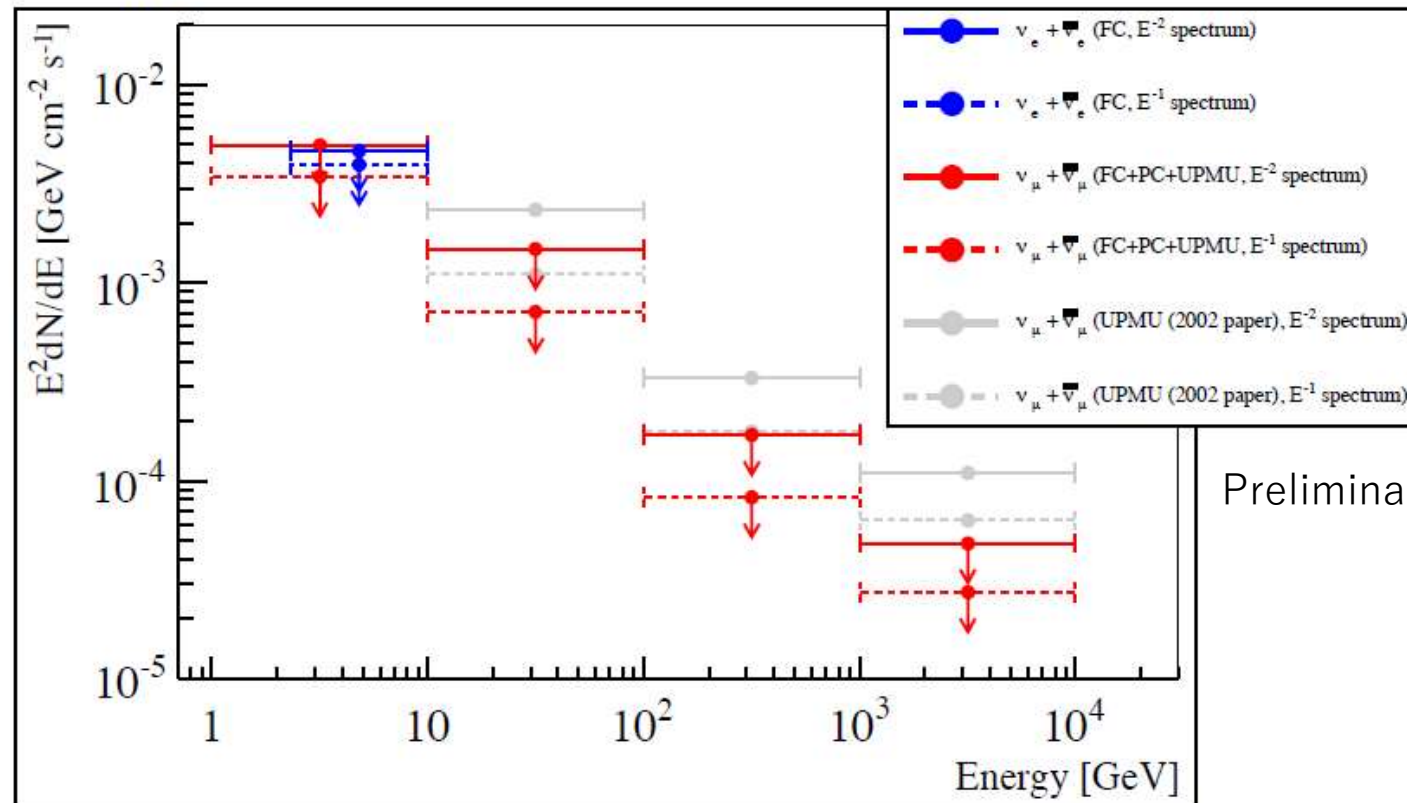
Fluence

$$\Phi = \frac{\left[\int_{E_{min}}^{E_{max}} \frac{\lambda(E_\nu)}{\Phi_{ind}(E_\nu)} dE_\nu \right]^{-1}}{nGRB} \text{ [cm}^{-2}\text{]}$$



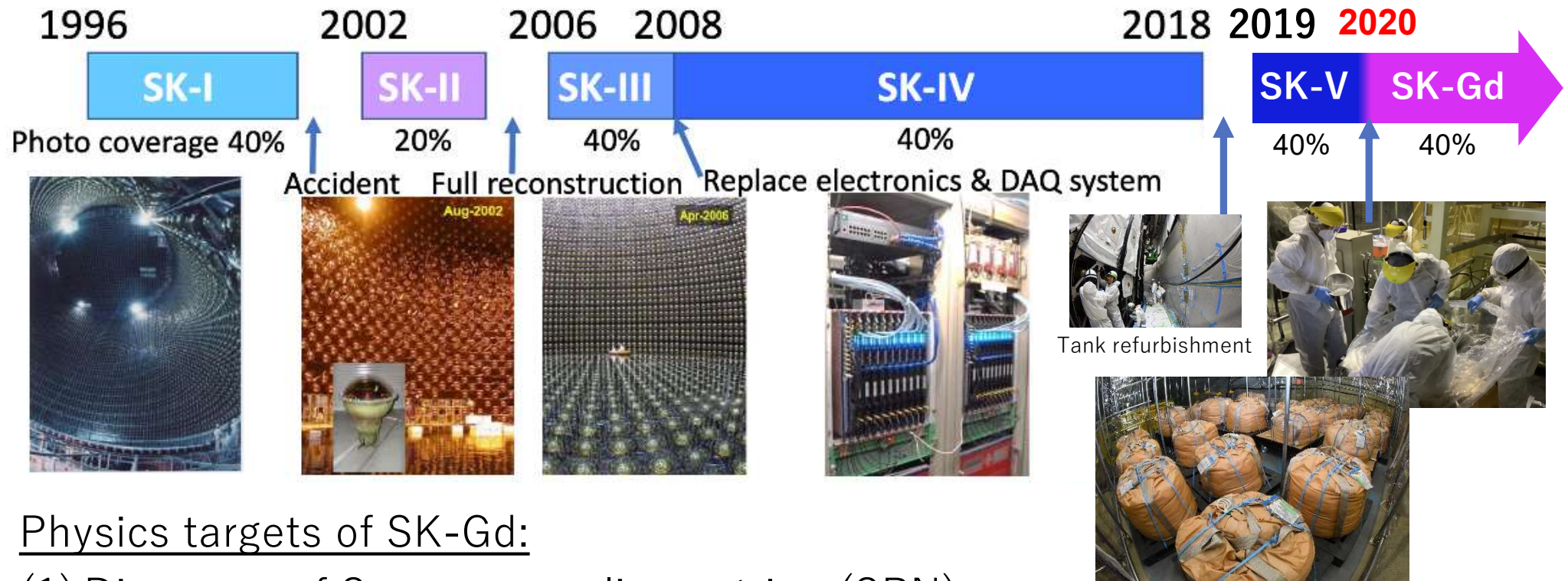
Energy flux

$$E^2 \frac{d\Phi}{dE} \text{ [GeV cm}^{-2} \text{ s}^{-1}\text{]} = E_c^2 \frac{\Phi}{E_{Max} - E_{min}} \times \frac{1}{T_{Ave}}$$



Preliminary

Super-Kamiokande Gd project just started

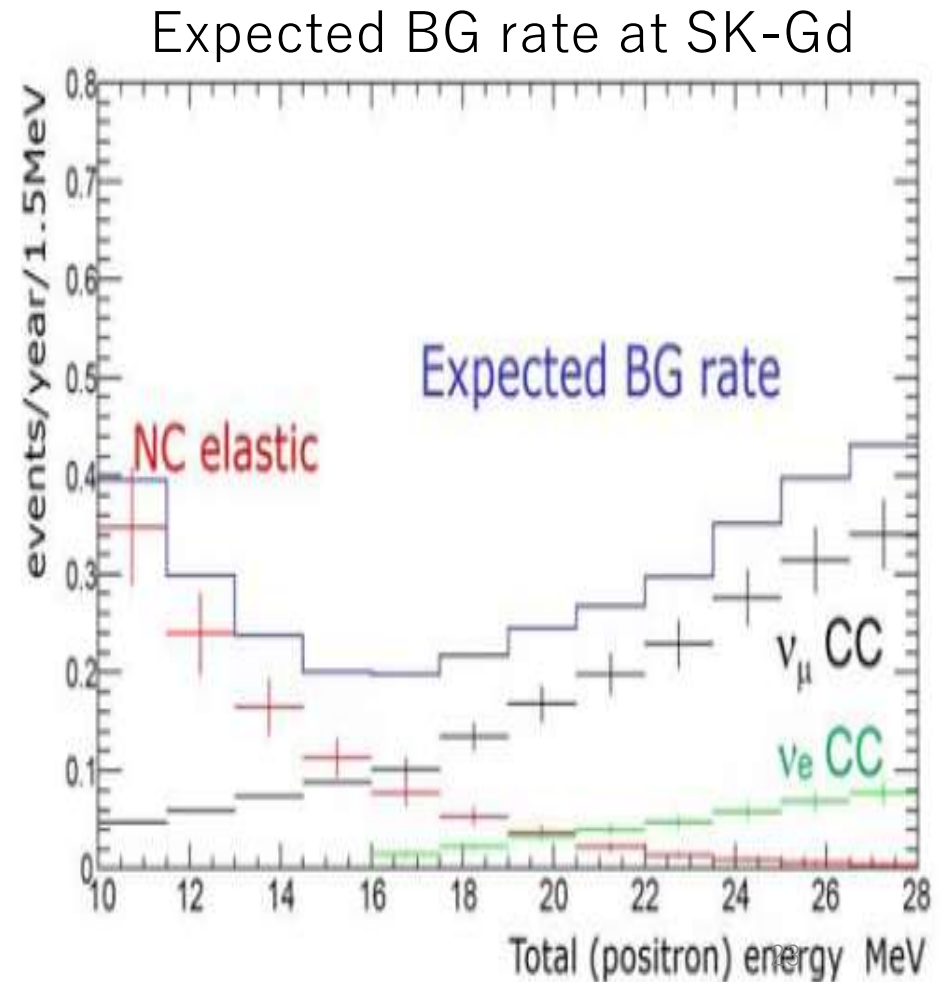


Physics targets of SK-Gd:

- (1) Discovery of Supernova relic neutrino (SRN)
- (2) Galactic supernovae (pointing accuracy, and Si-burning ν)
- (3) Reduction of BG for proton decay, solar ν , or reactor ν , GRB ν
- (4) Neutrino/anti-neutrino discrimination

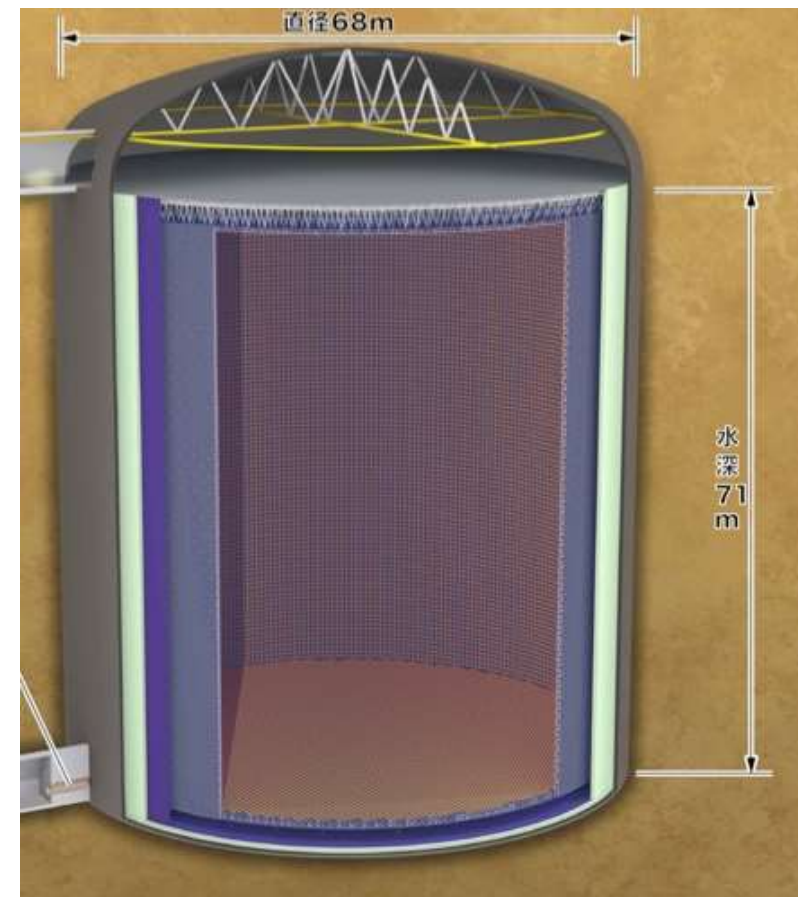
Prospect of SK-Gd (MeV ν search)

- Below 15 MeV:
 - Dominant BG is spallation product
 - With IBD tag, only Li9 will remain.
 - ~ 2 events/year is expected
- Above 15 MeV:
 - Dominant BG is atmospheric nu
 - With IBD tag, $\sim 1/4$ of current BG
- Expected sensitivity after 10 years observation with SK-Gd.
Improvement from current limit
 - Below 15 MeV : $\sim 1/6$
 - Above 15 MeV : $\sim 1/2$



Hyper-Kamiokande

- Target : SK \times 8
- Below 15 MeV:
 - Overburden \sim 600m (SK:1000m)
 - Spallation product density \sim SK \times 3
 - Spallation BG : \sim SK \times 8 \times 3
 - See more detail for HK design report
<https://arxiv.org/pdf/1805.04163.pdf>
- Above 15 MeV:
 - Atmospheric BG : \sim SK \times 8
- Expected sensitivity after 10 years observation with HK
Improvement from current limit
 - Below 15 MeV : $\sim \sqrt{8 \times 3} / 8 \sim 60\%$
 - Above 15 MeV : $\sim \sqrt{8} / 8 \sim 35\%$



Fiducial volume : \sim SK \times 8

Summary

- GRB search with SK.
 - $O(10\text{MeV})$; No significant signal found
 - $O(100\text{MeV}-10\text{TeV})$; No significant signal found
 - Improved upper limits are obtained.
- Future prospect
 - SK-Gd: Spallation BG will be reduced a lot.
 - HK: Large improvement especially at higher energy region.