Search for astronomical neutrino from the Gamma-ray burst with Super-Kamiokande

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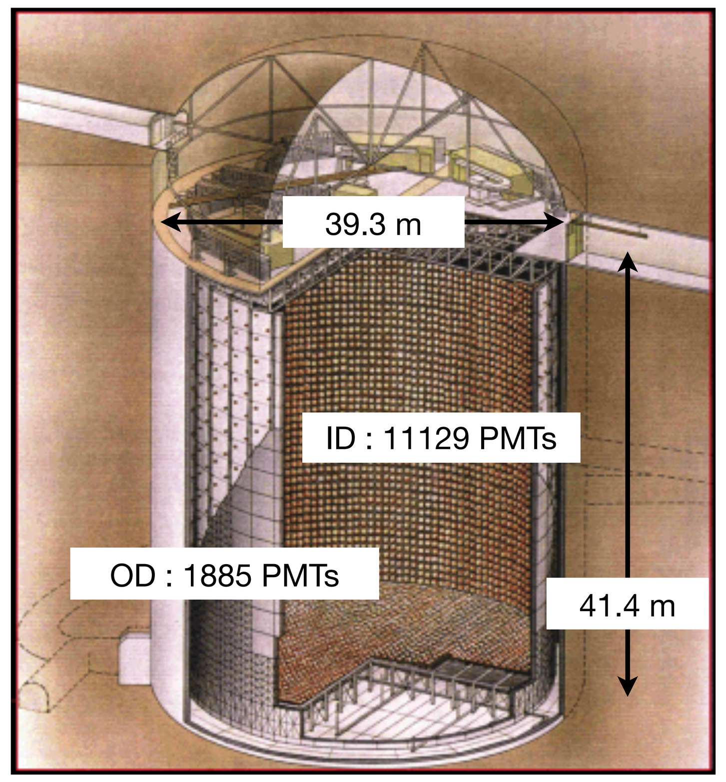
Introduction

- Gamma-Ray Burst (GRB) is the brightest object in the Universe. GRBs are interesting as an electromagnetic counterpart of Multi-messenger astronomy.
- Many theoretical models predict the **neutrinos are also emitted** from GRB object with Gamma-rays. But the neutrinos associated with GRB have not been detected yet. Neutrino detection would be really helpful to understand the dynamics of the GRB objects.
- GRB is observed about once a day. IceCube group record each GRB event observed by various detectors on GRBweb†. Timing and direction information of GRB detection is useful for neutrino search coincident with GRB.
- The **±500 s time window** is derived for taking into acount any time difference from GRB.

†https://icecube.wisc.edu/~grbweb_public/

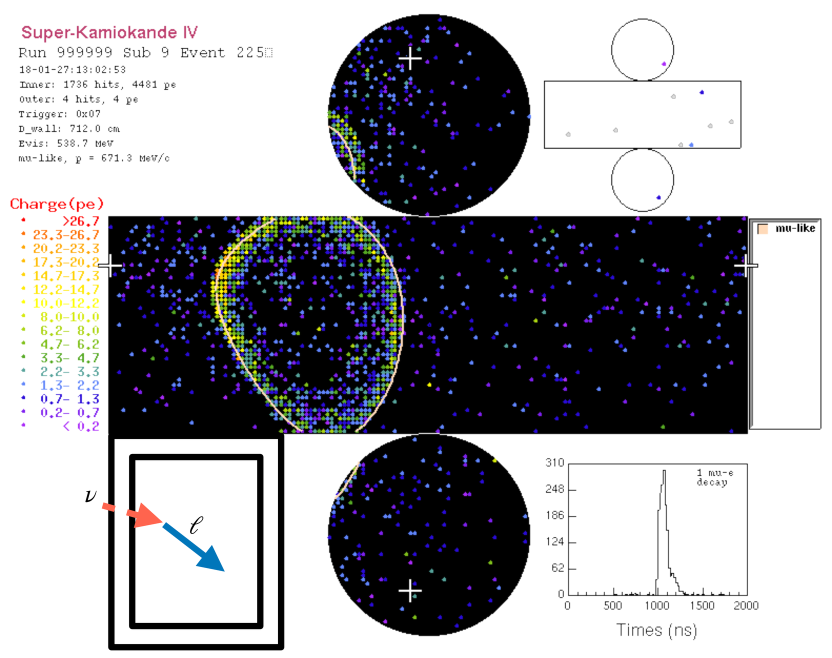
Detector | Super-Kamiokande (SK)

- SK is a large Water-Cherenkov detector, running since 1996.
- Consist of 50 kton ultra-pure water as the target for neutrino.
- Location is 1000 m under the peak of Mt Ikenoyama, Japan.
- Detector is separated optically, into Inner Detector (ID) and Outer Detector (OD) for event VETO.
- Apr. 1996 - Feb. 2018 data are used. Total live time 5924.4 days.



Data sample of high energy event

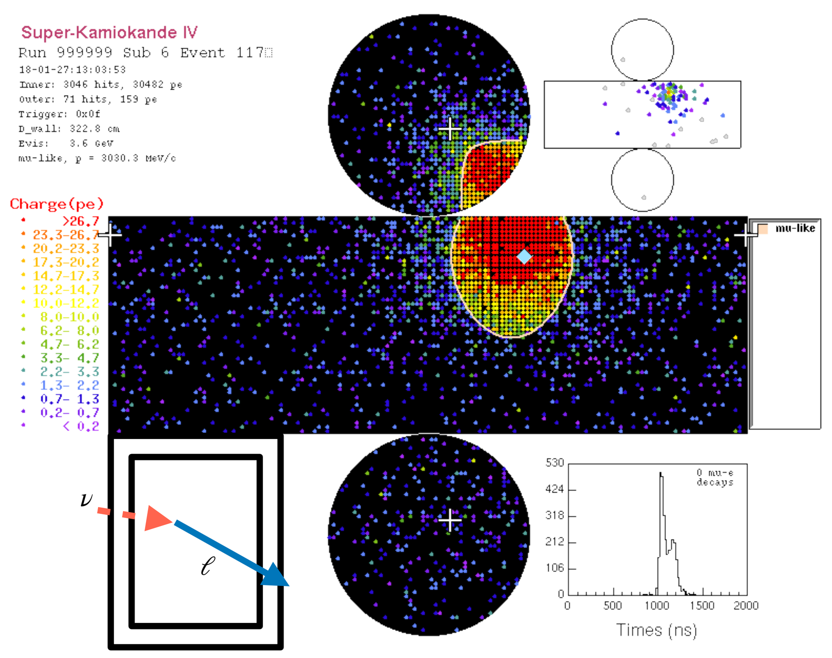
Fully-Contained (FC)



Coverage | Full-sky

Energy range | 0.1 - 10 GeV

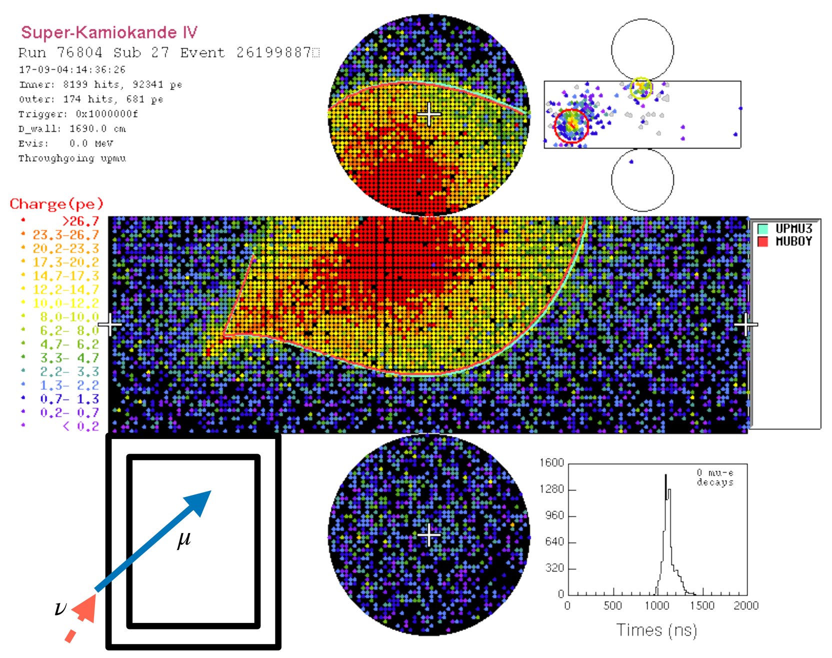
Partially-Contained (PC)



Coverage | Full-sky

Energy range | 1 - 100 GeV

Upward-going muon (UPMU)



Coverage | Only below the SK

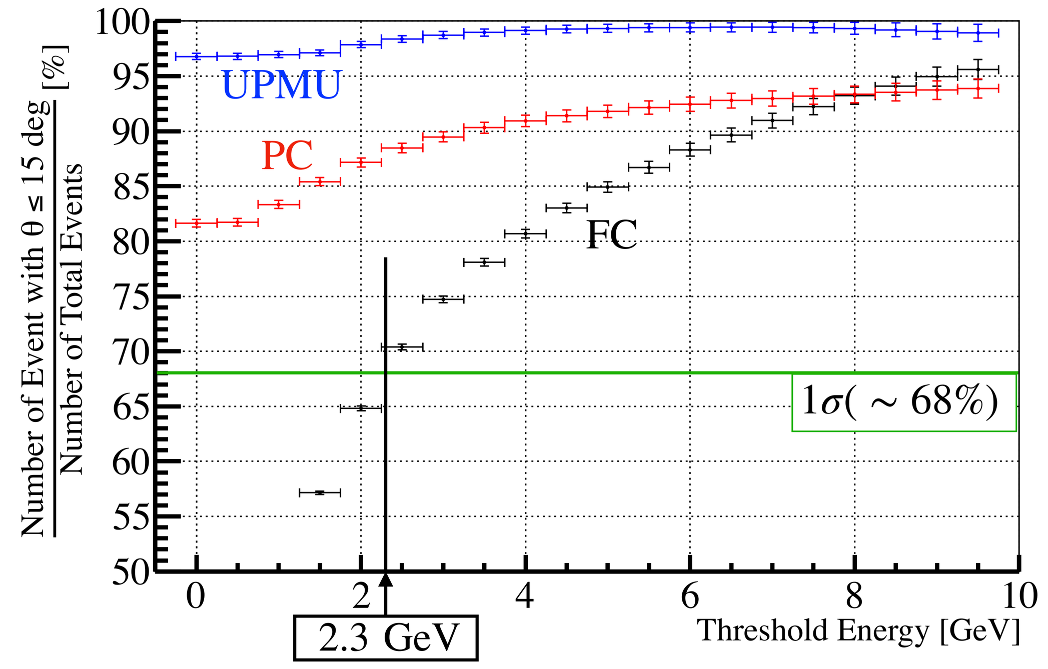
Energy | 1.6 GeV- 10 TeV

- Atmospheric Neutrinos are dominant background above 100 MeV,
- Only upward GRBs are considered for UPMU sample. Therefore, the number of target GRBs, for which the time window is completely contained in SK running time, are 3737 for FC and PC, 1737 for UPMU.

Data selection

Neutrino event with timing within 1000 s window, and direction within 15 degrees from GRB are selected.

- To use direction information, energy threshold is applied for reconstructed charged-particle.
- Probability that a direction will be reconstructed within 15 degrees of the true neutrino direction is calculated, using atmospheric neutrino Monte-Carlo(MC) simulation. Energy threshold with a 68% probability is selected.



Energy threshold of **2.3 GeV** is set for FC event.

Result

Summary of search results

There were 3 events in SK live time

	GRB970317A	GRB 990711B	GRB 991004F
Data Type	FC	FC	UPMU
Angle from GRB	11.8°	12.0°	3.6°
Energy	4.27 GeV	3.80 GeV	7.96 GeV
Timing from GRB trigger	278.2 s	263.0 s	411.2 s
GRB duration time	70.1 s	1.1 s	79.9 s

	Data	Background	90% C.L.
FC	2 ± 1.4	0.77	4.6
PC	0	0.48	2.3
UPMU	1 ± 1.0	0.76	3.4

Expected background is evaluated from 500-year-equivalent atmospheric neutrino MC.

No significant excess from the expected background. The 90% C.L. limit for the number of neutrino event are derived for each sample, by using this formula :

$$\int_{N_{bg}}^{N_{bg}+N_{90}} dx\,\mathrm{Poisson}(N_{obs}, x) = 0.9 \int_{N_{bg}}^{\infty} dx\,\mathrm{Poisson}(N_{obs}, x)$$

Limit calculation

- Fluence Φ [cm^{-2}] and energy-flux E^2dN/dE [GeV cm^{-2} s^{-1}] limit were derived from search results and using detector information.
- e-type neutrino is considered only FC event. PC and UPMU consider only muon-type.

$$\Phi^{\nu_x+\bar{\nu}_x}_{FC(PC)}(E_\nu)\ [\mathrm{cm}^{-2}] = \frac{N_{90}^{FC(PC)}}{N_T \int_{E_{min}}^{E_{Max}} dE_\nu \left(\sigma_{\nu_x}(E_\nu)\epsilon_{\nu_x}(E_\nu) + \sigma_{\bar{\nu}_x}(E_\nu)\epsilon_{\bar{\nu}_x}(E_\nu)\right)\lambda(E_\nu)} \times \frac{1}{\mathrm{nGRB_{FC(PC)}}}$$

Cross-section×Detection efficiency

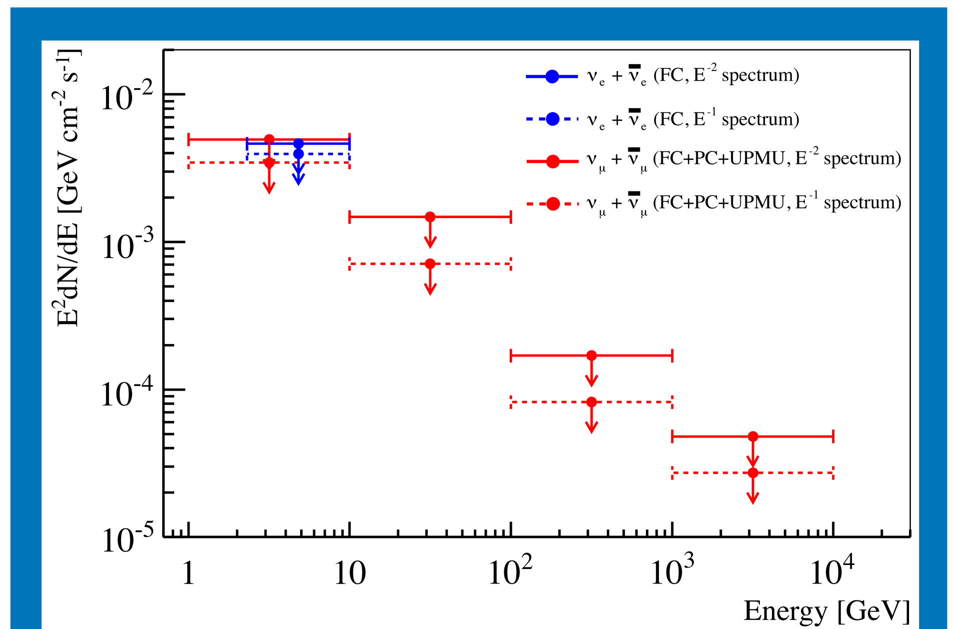
$$\Phi^{\nu_\mu+\bar{\nu}_\mu}_{UPMU}(E_\nu)\ [\mathrm{cm}^{-2}] = \frac{N_{90}^{UPMU}}{A_{\mathrm{eff}}(z)\int_{E_{min}}^{E_{Max}} dE_\nu \left(P_{\nu_\mu}(E_\nu)S_{\nu_\mu}(z,E_\nu) + P_{\bar{\nu}_\mu}(E_\nu)S_{\bar{\nu}_\mu}(z,E_\nu)\right)\lambda(E_\nu)} \times \frac{1}{\mathrm{nGRB_{UPMU}}}$$

Effective area; Muon generating prob.×Neutrino shadowing

$$E^2\frac{dN}{dE}[\mathrm{erg/cm^2/s}] = E_c^2 \frac{\Phi}{E_{Max} - E_{min}} \times \frac{1}{T_{Ave}}$$

E_{Max} : Maximum value of each bin
E_{min} : Minimum value of each bin
E_c : Center value of each bin

Spectrum λ assumes power law following E^{-2} and E^{-1} .



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