

Search for Astronomical Neutrino from Blazar TXS0506+056 in Super-Kamiokande

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For Super-Kamiokande Collaboration

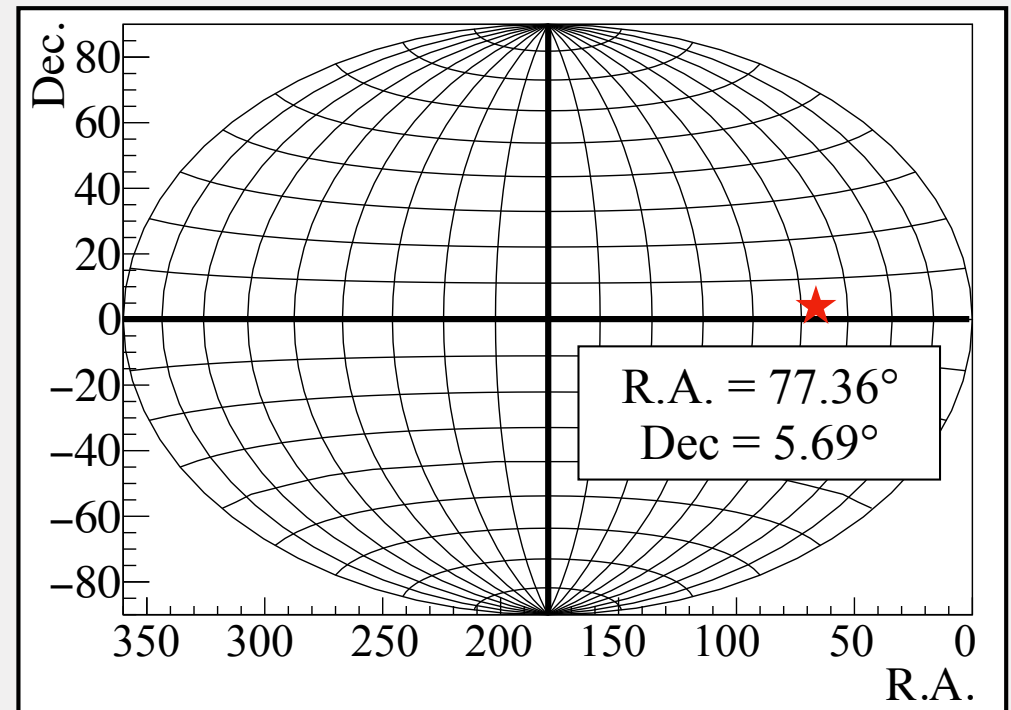
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Introduction

A high-energy neutrino (~ 290 TeV) was detected by IceCube on 22 September 2017. It was coincident in direction and time with a γ -ray flare from the blazar TXS0506+056. IceCube also had observed neutrino events from that direction at 2015 without a γ -ray flare.



I would like to search the neutrino event came from that direction in Super-Kamiokande

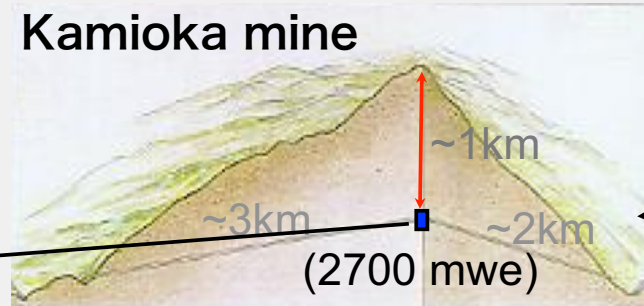
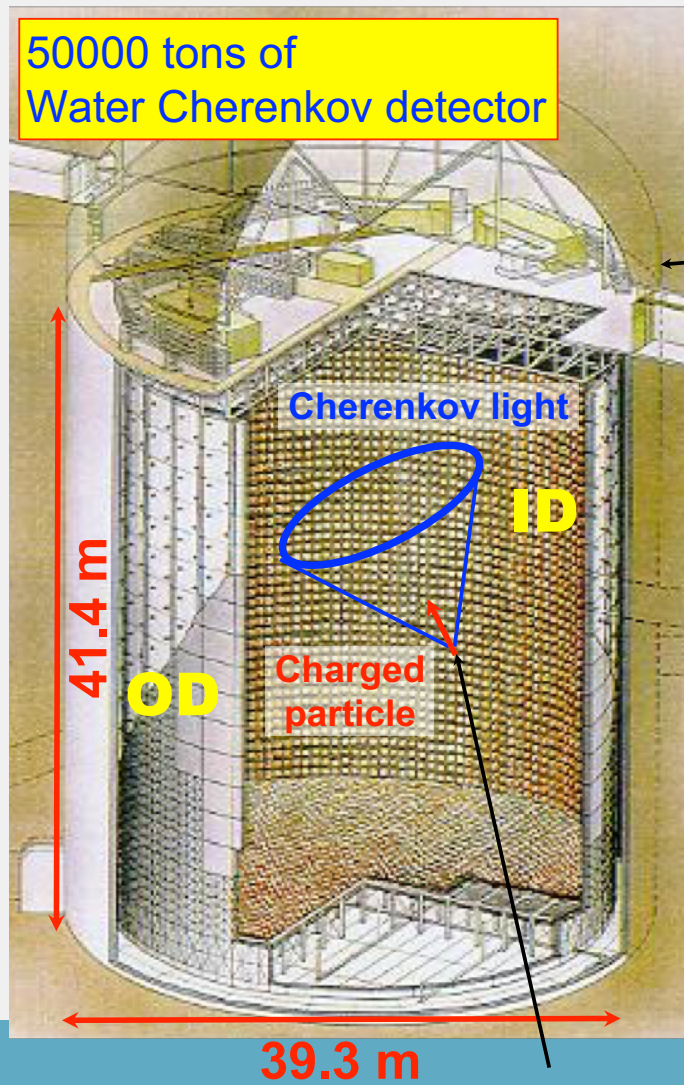


TXS 0506+056	
Distance	~ 1.75 Gpc (5.7×10^9 ly)
Right Ascension (R.A.)	77.3582°
Declination (Dec.)	+5.69314°

<http://science.sciencemag.org/content/361/6398/147.long>

Super-Kamiokande (SK)

The Super-Kamiokande is a large water Cherenkov detector which is located at 1000 m underground in the Kamioka-mine, Japan. The SK detector constructed a cylindrical tank has a 50 kilotonne pure water as neutrino target. The tank is separated into an inner detector volume and an outer detector volume.

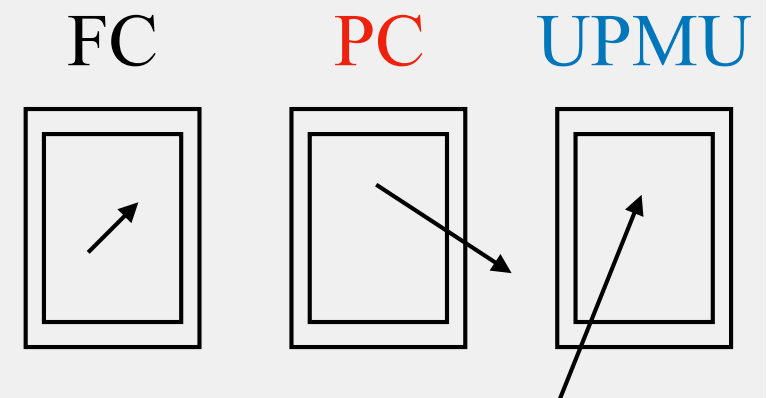
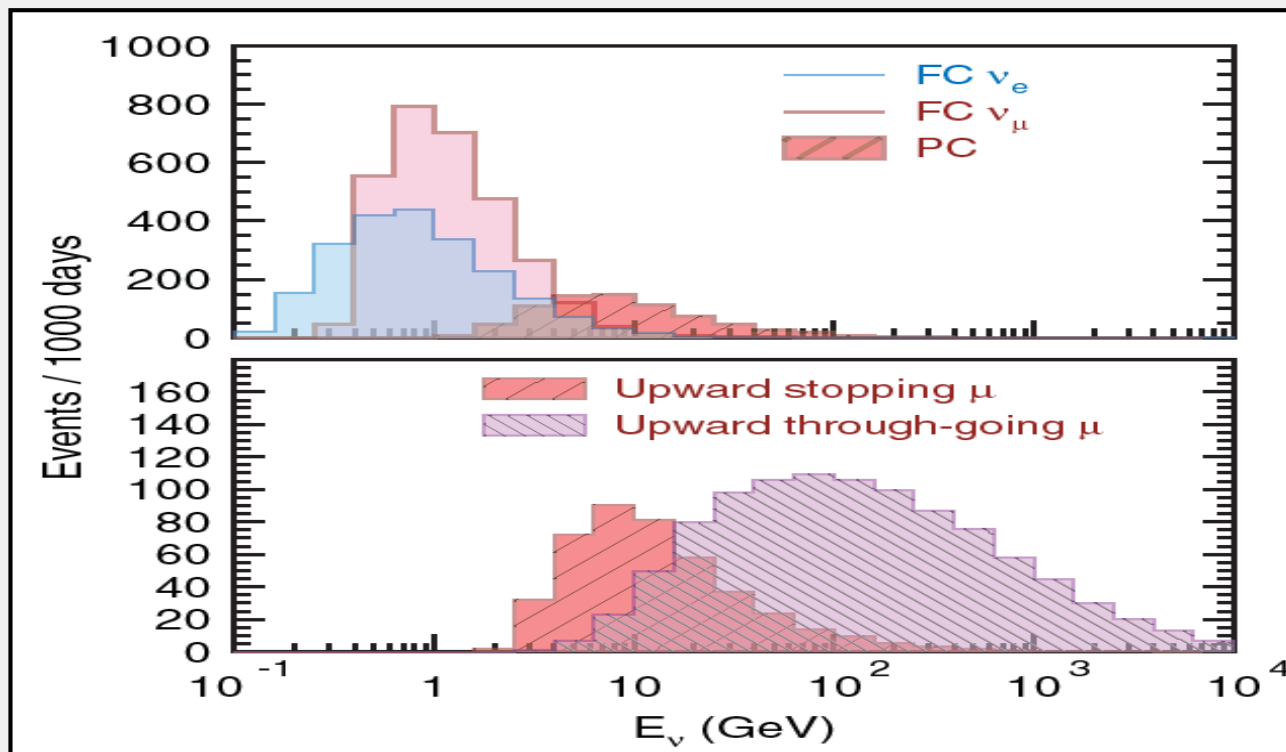


Phase	Period	Fiducial vol.	# of PMTs
SK-I	Apr.1996 - Jul.2001	22.5 kton	11146 (40%)
SK-II	Oct.2002 - Oct.2005		5182 (20%)
SK-III	Jun.2006 - Sep.2008		11129 (40%)
SK-IV	Sep.2008 - May.2018		
SK-V	Feb.2019-		

Dataset from Apr.1996 to Feb.2018 was used.

Category of Neutrino Event

The event that all daughter particles stop within the ID is categorized as fully-contained (**FC**). If any of the produced particles exit to the OD, it is categorized as partially-contained (**PC**). The energetic muon-neutrinos interacting with the rock around the SK create muons which enter the ID through OD. Only the muons with upward momentum are categorized as upward-going muon (**UPMU**) because down-going muon events of this kind could not be distinguished from cosmic muons.

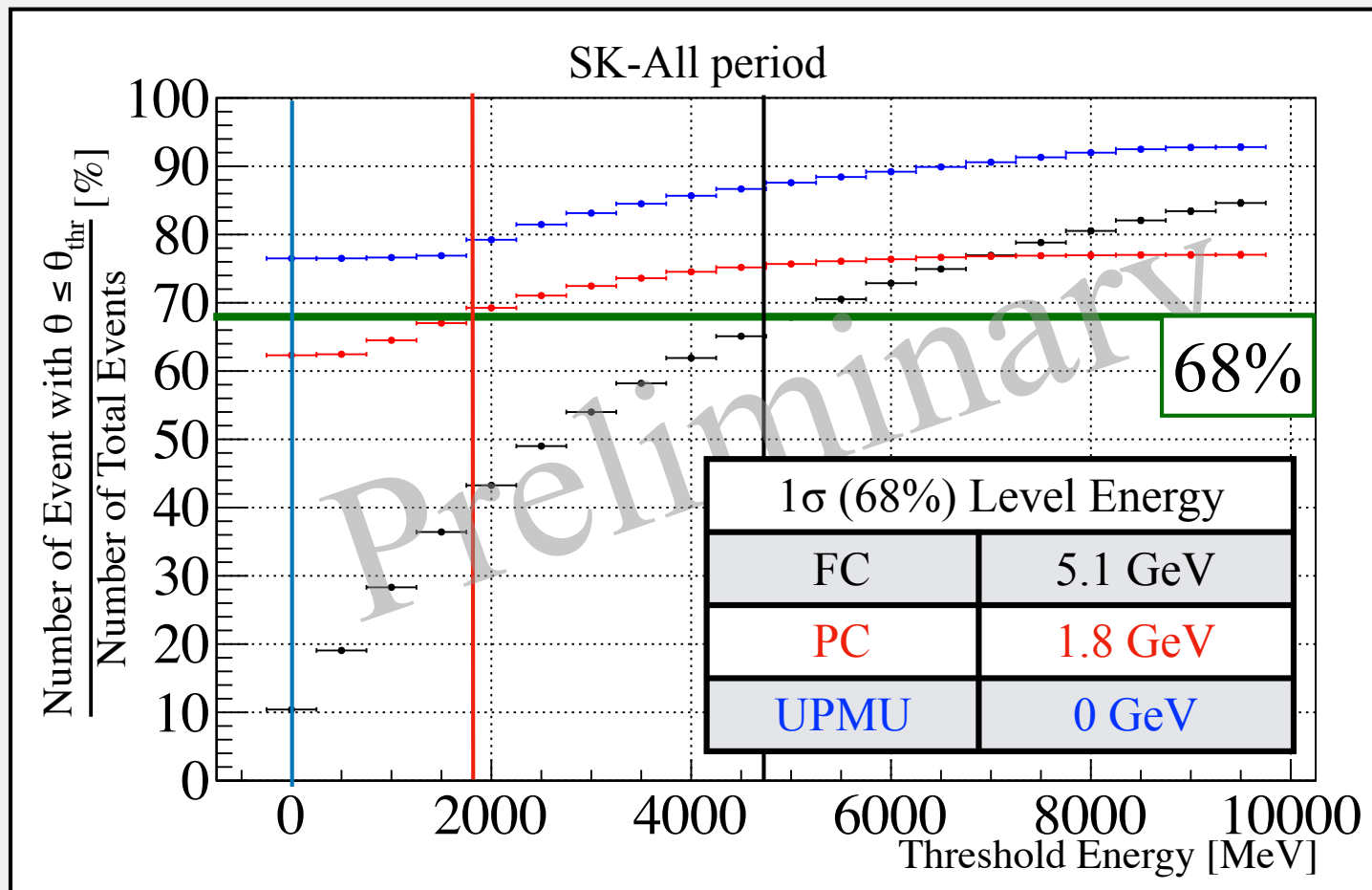


Astronomical Neutrino Search @ SK

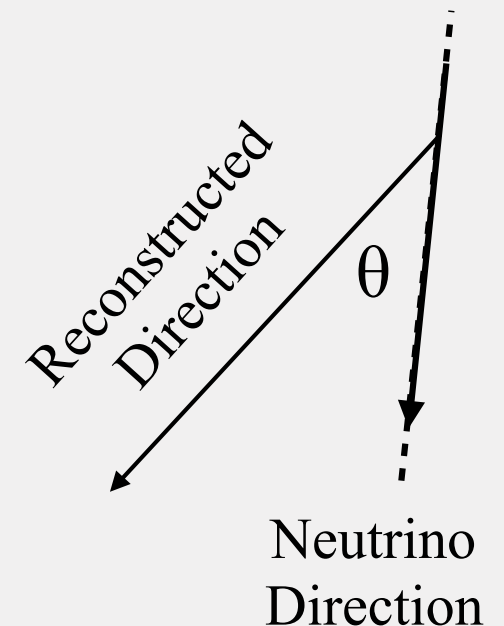
- ▶ Since SK and IceCube have different energy ranges that can be observed, we search for neutrinos focusing on low energy (MeV-GeV) regions.
- ▶ If the Blazar emits neutrinos over the whole observation period of SK, the neutrino flux is higher than the other direction.
- ▶ If the Blazar emits a large amount of neutrinos in a short time (coincident with gamma-ray flare), we can see a time-dependent significant signal.
- ▶ If no significant signal is seen against the expected background, an upper limit can be determined.

Angular Resolution

From MC simulation, the angle between the true neutrino direction and reconstructed direction was calculated for point source search. As a results, 68% of all events are included in the search cone (10° for FC and PC, 5° for UPMU) for energy cut.

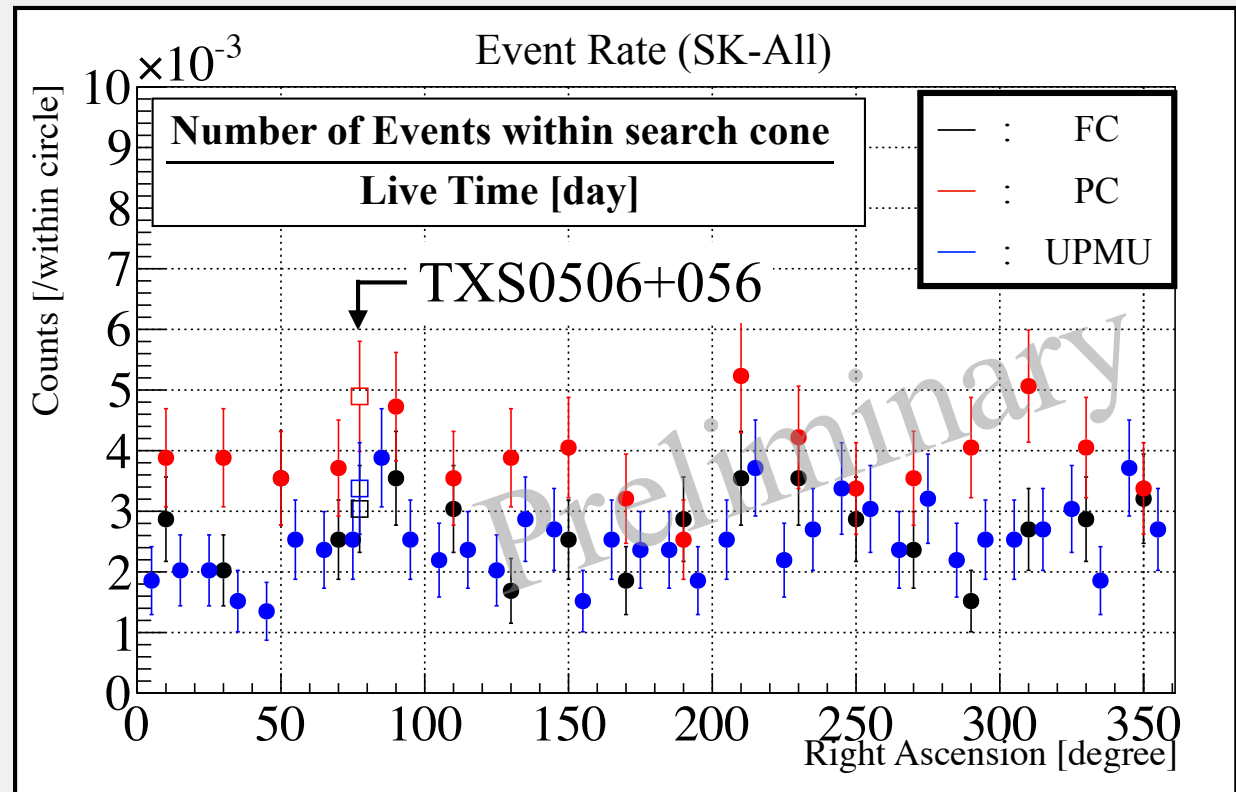


	FC, PC	UPMU
θ_{thr}	10°	5°



Event Rate

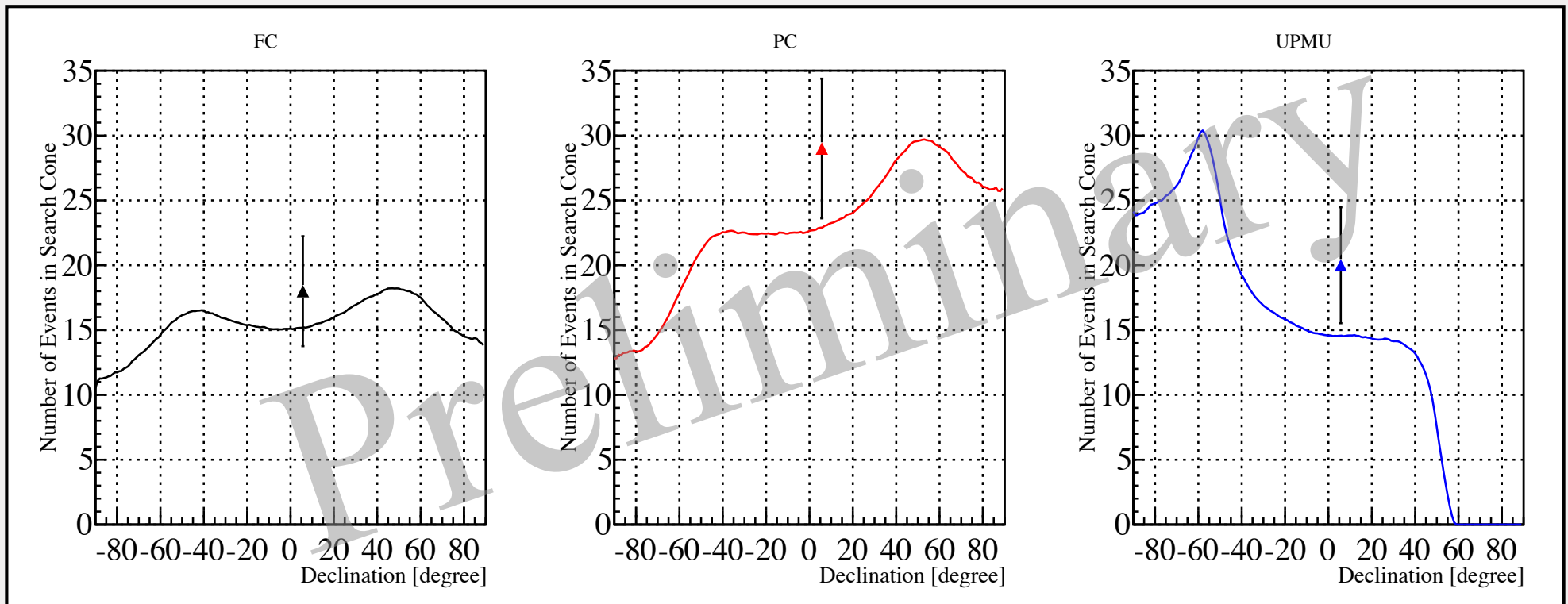
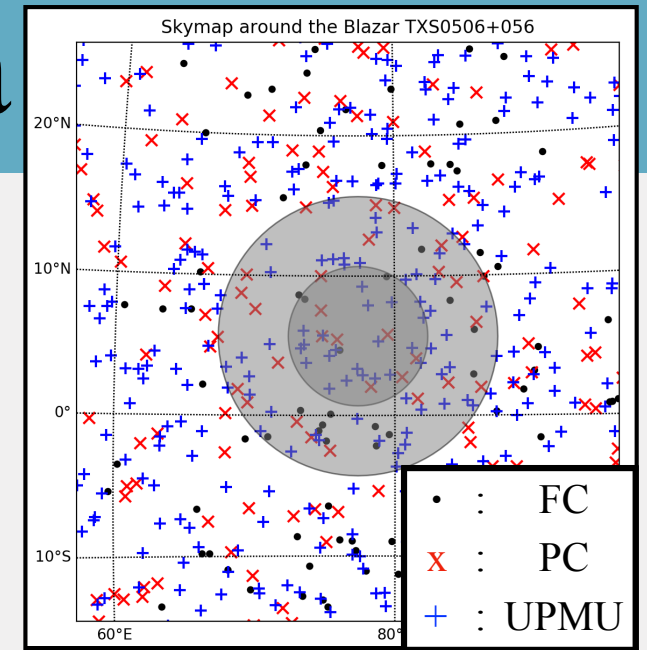
The event rate was compared with at off-source region. The errors for mean value of event rate without Blazar direction are calculated by RMS. The errors for Blazar direction are calculated by statistics. No significant signal was found.



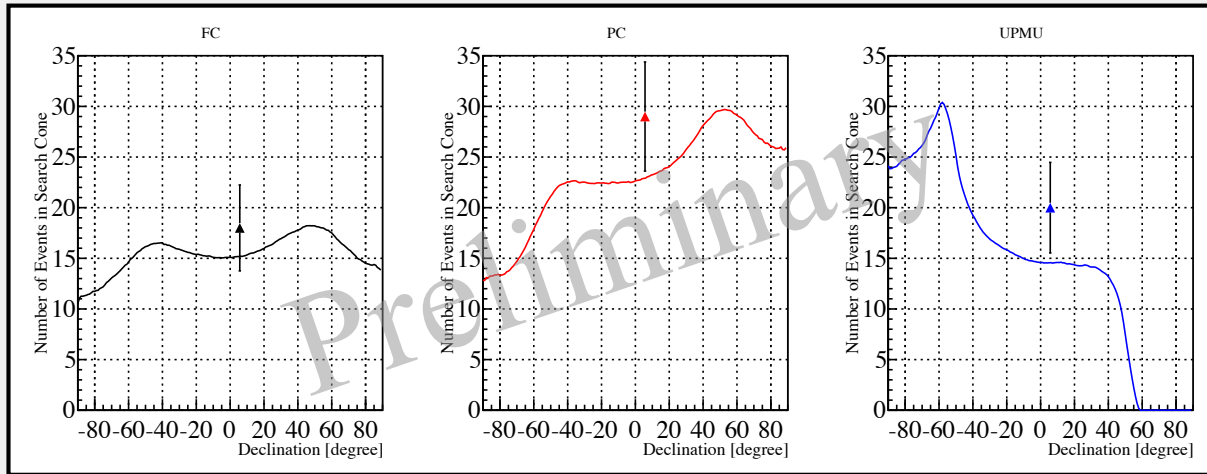
Event Rate [/ Live Time Day]	Mean Value of Event Rate w/o Blazar Direction	Blazar Direction
FC	0.0027 ± 0.0006	0.0030 ± 0.0007
PC	0.0039 ± 0.0006	0.0049 ± 0.0009
UPMU	0.0025 ± 0.0006	0.0034 ± 0.0008

MC and Experimental Data

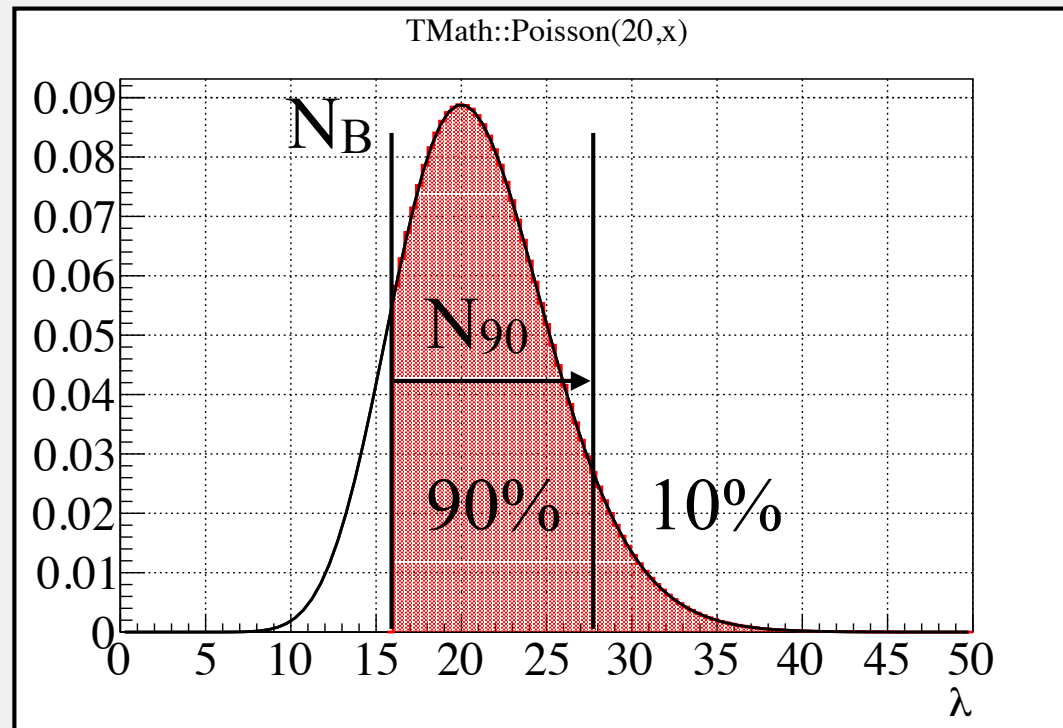
The expected background was estimated by MC. The observed events inside a search cone agree with expected background within 0.7σ for FC, 1.1σ for PC, and 1.2σ for UPMU.



90% Confidence Level



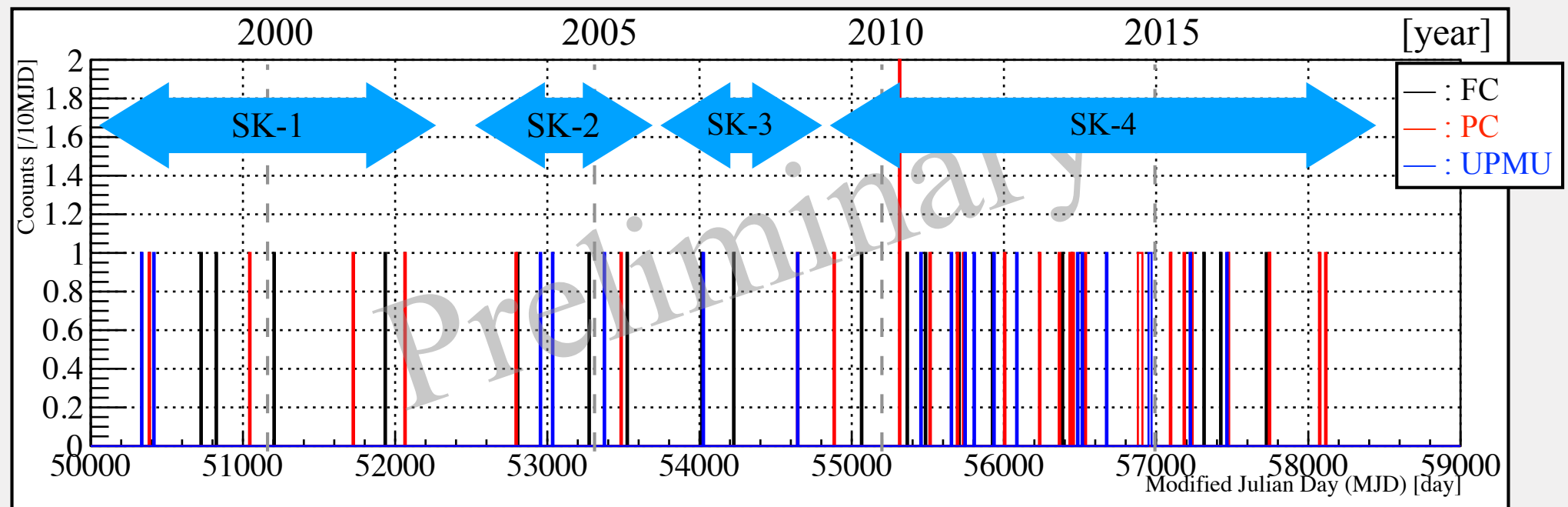
The number of 90% Confidence Level (C.L.) was determined from the number of observed events against the expected number of background events using a Poisson distribution.



	Background Events (N_B)	Observed Events (N)	Events of 90% Confidence Level (N_{90})
FC	15.2014	18	10.186
PC	22.9062	29	14.623
UPMU	14.5687	20	12.688

Search for Time-Dependent Excess by KS-test

If there is a relationship between the gamma-ray flare of the blazar and emission of neutrino, the neutrino flux should increase depending on time. The P-value of KS-test was calculated. The results were 61.08%, 41.17%, and 98.33% for FC, PC, and UPMU events. It can not be said that it does not agree with the stable event rate (P-value < 5%). The significant time-dependent excess was not found.



Summary

- A high-energy neutrino detected by IceCube was coincident in direction and time with a γ -ray flare from the blazar TXS0506.
- ☑ The event rate focused on the blazar direction was constant with other direction.
- ☑ From MC data, the background events depended on declination was estimated. The experimental data agrees with the expected background within 0.7σ for FC, 1.1σ for PC, and 1.2σ for UPMU events.
- ☑ From the results of the Kolmogorov-Smirnov test, no significant temporal event excess was found from blazar direction.