# Reexamination of Kamiokande-II data in 1987

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# Introduction

- **Three new topics from old Kamiokande-II experiment are presented.**

  ① **SN1987A neutrino burst**
  **Y.Oyama, Astrophys. J. 922, 223(2021)**
  **https://doi.org/10.3847/1538-4357/ac374b**

  ② **High energy neutrinos from SN1987A**
  **Y.Oyama, Astrophys. J. 925, 166(2022)**
  **https://doi.org/10.3847/1538-4357/ac4269**

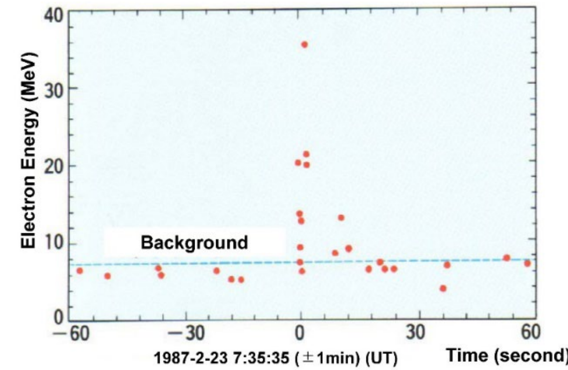
  ③ **Correlation of two successive events**

- **A ~50 minutes version of the presentation file can be found at**
  **https://www-nu.kek.jp/~oyama/kam30yrs.oyama.210422.pptx**

- **Why data of more than 30 years ago. Why now ?**
  **--- Please visit my backup slide**

# ①SN1987A neutrino burst

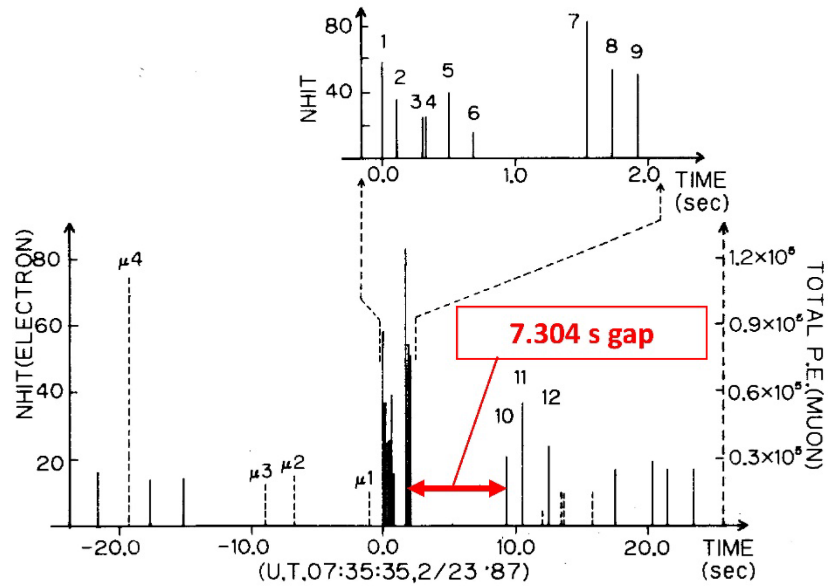
# Neutrino burst from SN1987A – seven second gap




- The Kamiokande-II collaboration successfully observed the neutrino burst from SN1987A. Eleven neutrino events are detected during 13 seconds.

- In the Kamiokande-II original paper, another time-energy plot are shown instead the famous plot.

- In this plot, the 7.304s time gap between the 9th event and the 10th event is very clear.




- Why there was a gap?
  The "seven seconds gap problem".

- Let me pull your attention to the gap again ! In the 7.304s gap, you can find no cosmic ray muon events, whose rate is ~0.37Hz. Surprisingly, no cosmic ray muon event was detected in ~13 seconds of the supernova neutrino period!

- In addition, you can find no low energy background events (mostly coming from radio activities) , whose rate is ~0.15Hz.

# Chance Probability

- The **chance probability** for "no SN1987A neutrino" and "no cosmic ray muon" and "no low energy background" in $\Delta t$=7.304s is calculated..

| | Rate | Expected # in 7.304s | Calculation | Probability of 0 event |
|---|---|---|---|---|
| SN1987A neutrino | | | K.S.Hirata* | <0.05 |
| Cosmic ray muon | ~0.37Hz | 2.70 | Poi(0\|2.70) | 0.067 |
| low energy B.G. | ~0.15Hz | 1.10 | Poi(0\|1.10) | 0.334 |

Poisson distribution : $Poi(n|\lambda)=\lambda^n e^{-\lambda}/n!$

*K. S. Hirata, Master thesis, Univ. Tokyo, 1988

- The chance probability is P < 0.05 x 0.067 x 0.334 = 0.00112.
- The chance probability 0.112% cannot be accepted. Is there dead time of the Kamiokande-II detector?

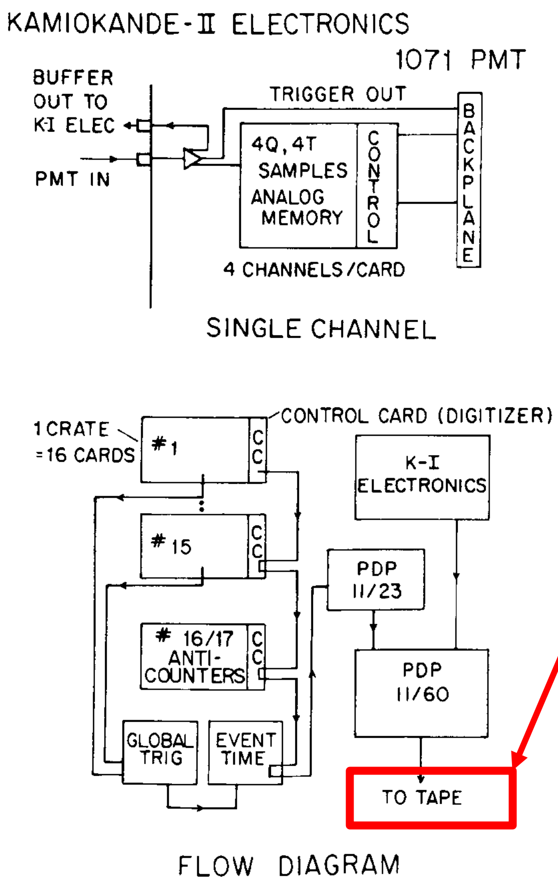
Above discussion is based on published results. Everybody can obtain similar results.

# What happened during the seven seconds?

- “Is there any reasonable explanation for the 7.304s dead time?”
It was a longstanding question for me.

- One day (after Prof. Koshiba's Nobel prize), I happened to see one figure that caught my attention. It was the block diagram of the Kamiokande-II electronics shown in the SN1987A full paper.

K.S.Hirata et al., Phys.Rev.D 38,448(1988)

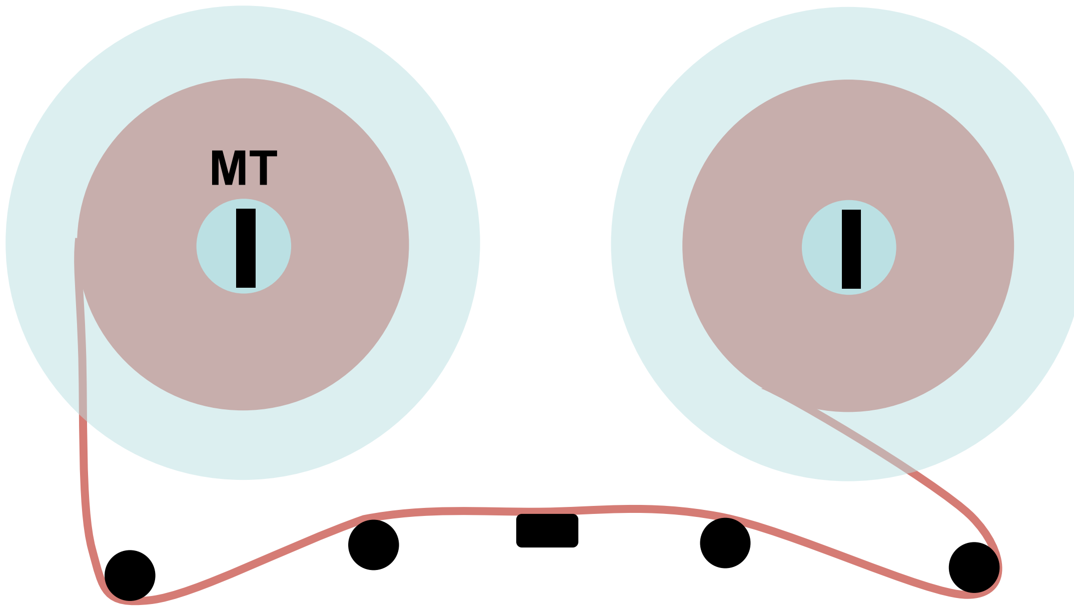



**Data were recorded to MT directly!**

MT (magnetic tape)
2400ft, 6250 bpi
180 MByte

# Write error and retry

- When the data were recorded to MT, "write error" occasionally happened. Partial rewind and retry were automatically done, and it took ~10 seconds for the recovery. During that time, the data buffer in the computer memory was full, and no new data could be accepted.




- In fact, "Kamiokande-II shift manual" had following instruction:
  To avoid frequent "write error", clean the head of the MT recorder by isopropyl alcohol when you mount the MT.
- The "write error and retry" might explain the cause of possible "seven seconds gap". Of course, nothing can be verified.

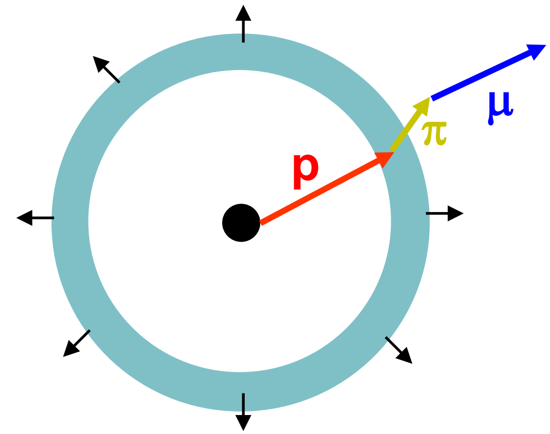
# Summary ①

- The chance probability for “no SN1987A neutrino” and “no cosmic ray muon” and “no low energy background” in 7.304s is 0.112%.
- There exists a reasonable explanation for the seven seconds dead time. It is “write error and retry” during writing to MT.
- We cannot deny the possibility that “seven seconds gap” during the SN1987A neutrino burst was “seven seconds dead time” of the Kamiokande-II detector.

# ②High energy neutrinos from SN1987A

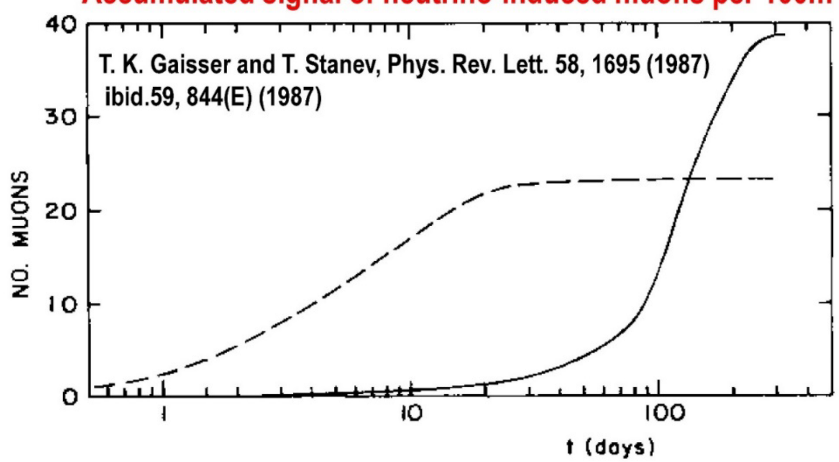
# High energy neutrinos from SN1987A

- High energy (> GeV) neutrinos could be generated from supernova remnants just after the explosion.
- Target material is thick gas which initially comprised the envelope of the progenitor and later diffused at the supernova explosion.

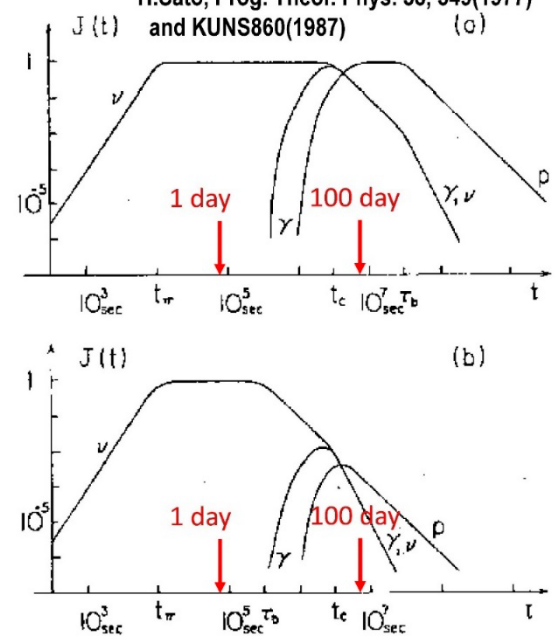



- Number of high-energy neutrino events from SN1987A and their time structure were calculated by theorists.
- They are strongly mode-dependent, but 10~100 upward-going muon events could be observed within one year from the explosion.

Accumulated signal of neutrino-induced muons per 100m$^2$




H.Sato, Prog. Theor. Phys. 58, 549(1977) and KUNS860(1987)



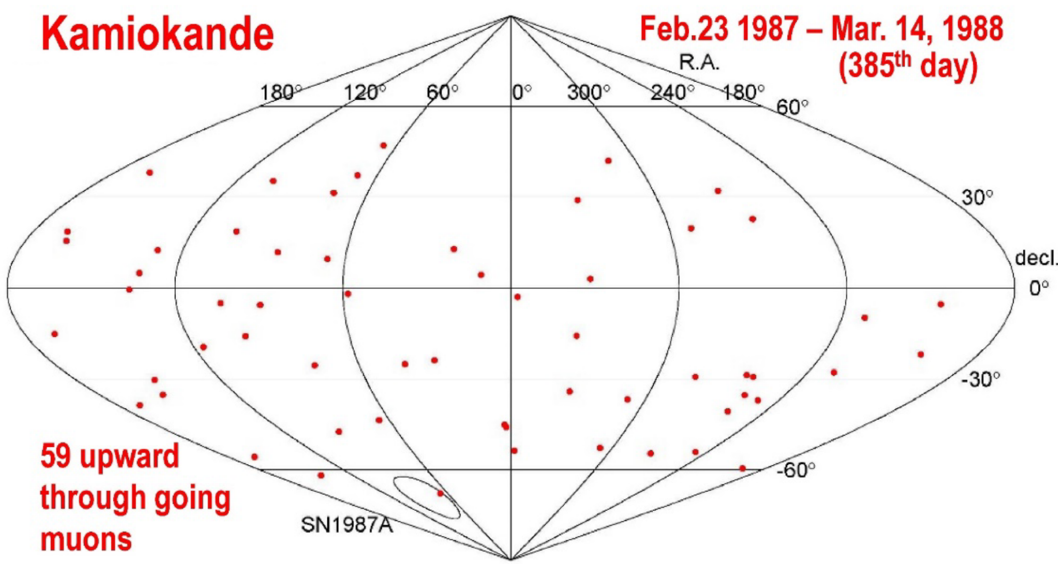
# “Published” Kamiokande results

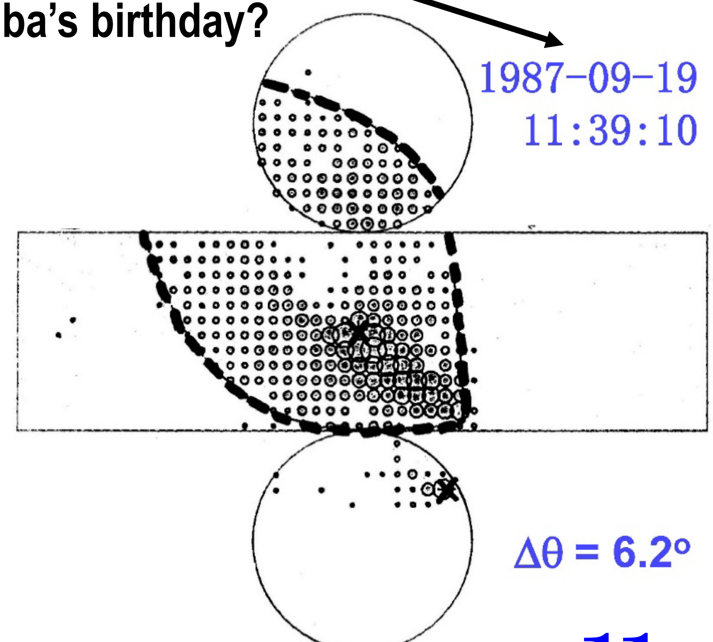
Y. Oyama et al., Phys.Rev.Lett. 59,2604(1987), Feb. 23, 1987 – Sep. 1, 1987 (191st day)

Y. Oyama, Ph.D thesis, ICR-Report-193-89-10, Feb. 23, 1987 – Mar. 14, 1988 (385th day)

- From the $\Delta\theta$=7.0° angular window, only 1 upward through-going muon event was found.
- Expected background from atmospheric neutrino is ~0.4.
- No significant signal was found.

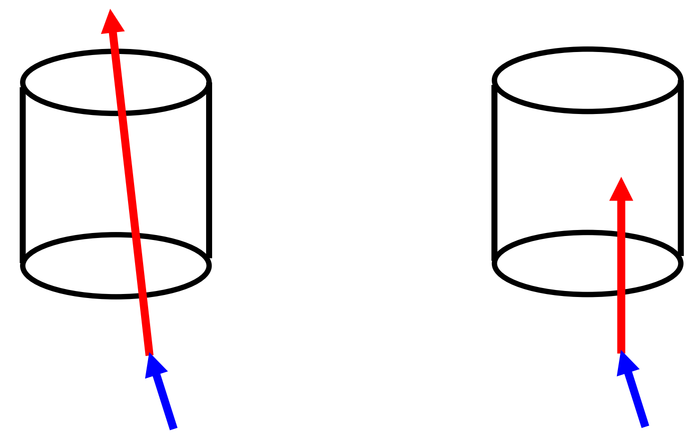
SN1987A celebrated Koshiba’s birthday?



# Upward stopping muon events

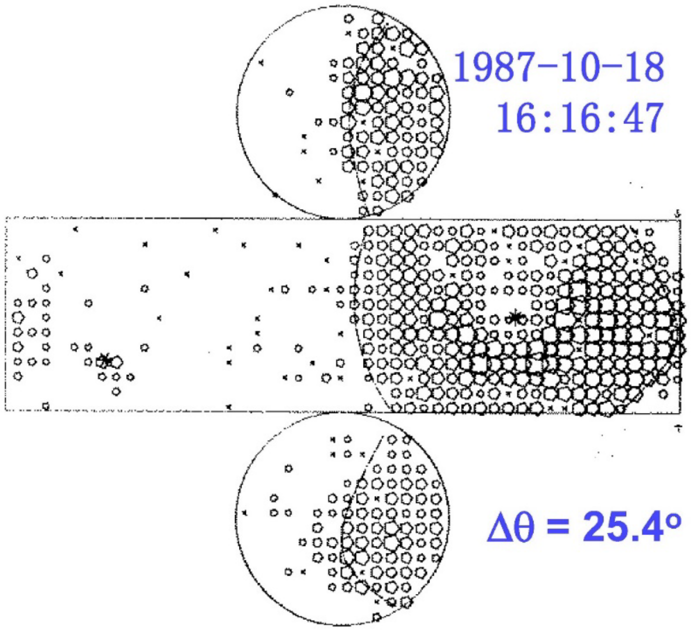
- It was not published, but we found **2 upward stopping muon events** from the SN1987A direction.
- They are upward-going muons which do not pass through the detector but stopped in the tank.
- We did not analyze upward stopping muon events systematically because of following reasons;

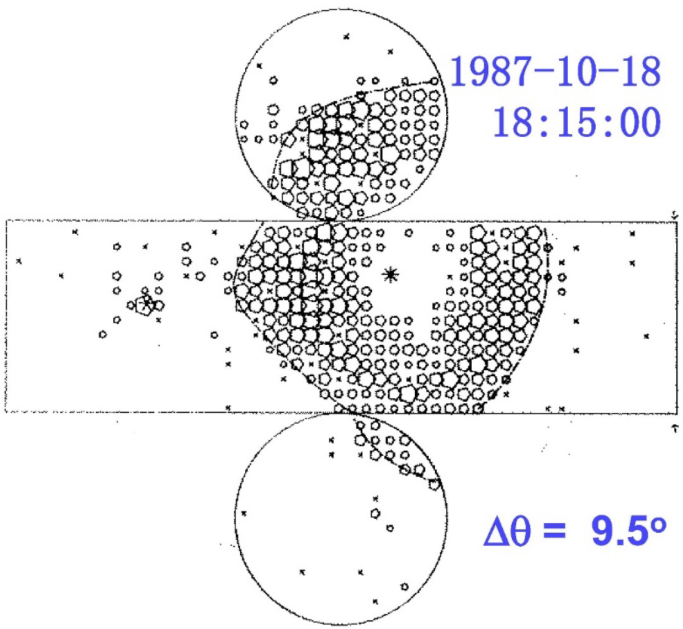



- ☐ The event rate is ~ 1/5 of upward through-going muons, and only **~11 events/year** are expected. Statistics is very poor.
- ☐ Angular correlations between parent neutrino and produced muon are poor. It means that the angular resolution is poor in the directional neutrino astronomy.
- ☐ The event selection was difficult, and the human power for the analysis was absent.

# Upward stopping muon events

- We can sometimes find upward stopping muon events during the event selection of upward through-going muons by visual scan because of similar event topology.
- We found **2 upward stopped muons in ~2 hours time duration** on **Oct. 18, 1987**. Note that angular resolution is poor for stopped muons.




- Even we combine with the upward through-going candidate, it is difficult to claim possible signal from SN1987A………

# Combine with IMB data !

- **IMB experiment is the other water Cherenkov detector which was operated in 1987. Many IMB members joined the Super-Kamiokande experiment later.**
- **When we worked together in Kamioka in 2004, they told us they also found some upward-going muon events from SN1987A direction around that period, but they are not statistically significant.**
- **They gave me the lists of the IMB upward-going muon events.**
  **- 666 through-going events (Sep. 1982 ~ Dec. 1990).**
  **- 34 stopping events (May 1986 ~ Feb. 1990).**
  **(Thank you, Prof. John G. Learned !)**
- **The IMB data was combined with Kamiokande-II, and we have 6 events.**

| | Date/Time (UT) | (RA, δ) | $\Delta\theta_{SN}$ | $\cos\Delta\theta_{SN}$ | category |
|---|---|---|---|---|---|
| 1 | 1987-08-12 5: 8:27 | (97.1°, -67.5°) | 5.2° | 0.996 | IMB-thru |
| 2 | 1987-09-19 11:39:10 | (67.2°, -67.9°) | 6.2° | 0.994 | KAM-thru |
| 3 | 1987-10-16 10:17:49 | (60.0°, -73.9°) | 8.7° | 0.988 | IMB-thru |
| 4 | 1987-10-18 16:16:47 | (18.8°, -63.5°) | 25.4° | 0.903 | KAM-stop |
| 5 | 1987-10-18 18:15:00 | (95.9°, -61.2°) | 9.5° | 0.987 | KAM-stop |
| 6 | 1988-01-13 3:23:27 | (67.4°, -64.0°) | 8.4° | 0.989 | IMB-stop |

# Let's define angular-time window and calculate the statistical significance!

- **The angular and time window are defined.**

  - $\Delta\theta_{SN} < 10.0^{o}$
  - between 1987-08-11 and 1987-10-20 (71days)

- **4 events remain in the angular-time window.**

| | Date/Time (UT) | (RA, δ) | $\Delta\theta_{SN}$ | $\cos\Delta\theta_{SN}$ | category |
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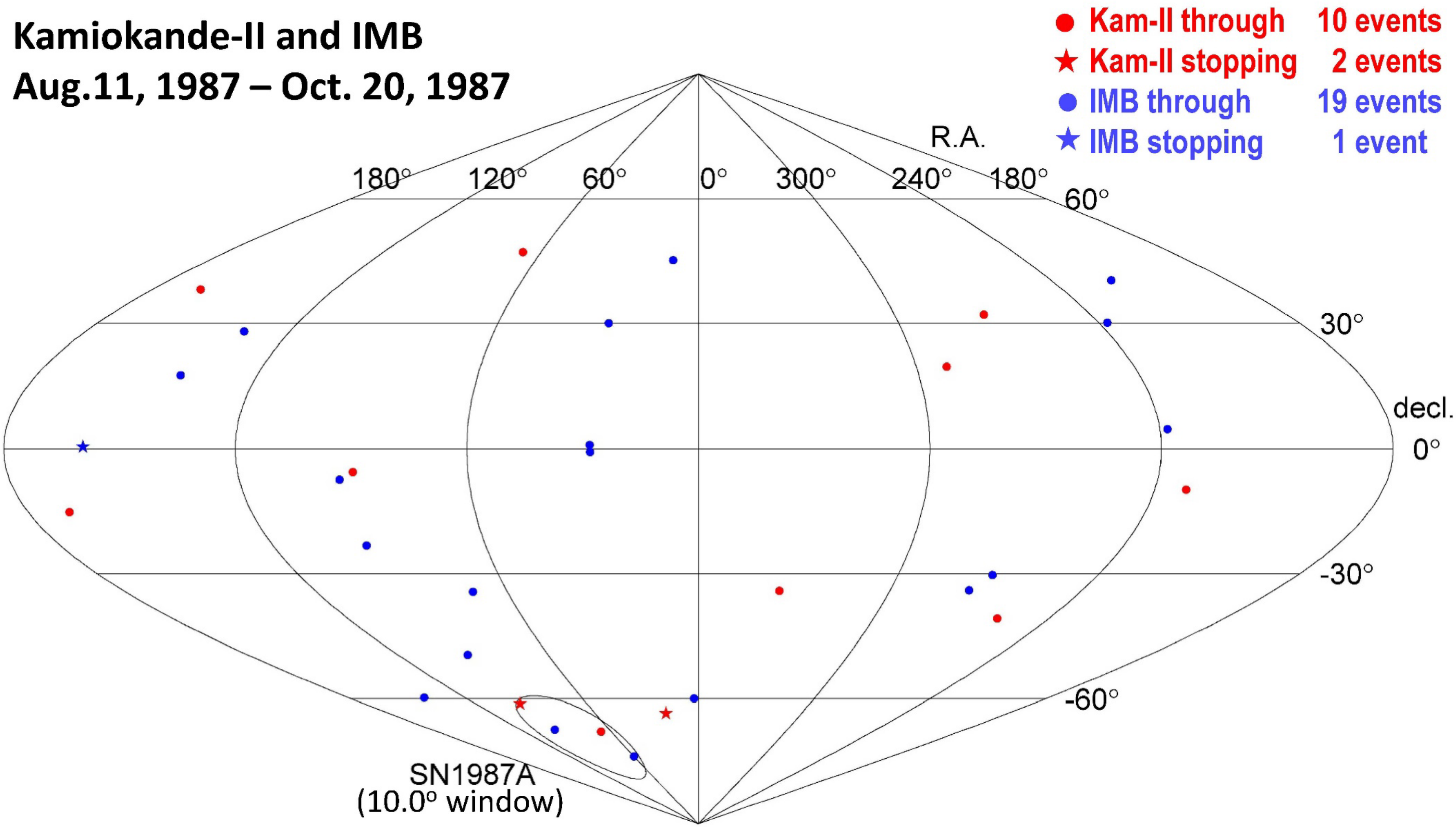
# Celestial map of upward-going muon events



# Chance coincidence of atmospheric neutrinos

- Number of upward-going muon candidates and expected atmospheric neutrino background are summarized in the table.

| category | # of candidates | Expected atm. ν B.G. (λ) |
|---|---|---|
| KAM-thru | 1 | 0.127 |
| KAM-stop | 1 | 0.026 |
| IMB-thru | 2 | 0.315 |
| IMB-stop | 0 | 0.029 |

- The probability that these signals are chance coincidence of atmospheric neutrinos is calculated.
- The probability of "$N_{Kam\text{-}thru} \geqq 1$ and $N_{Kam\text{-}stop} \geqq 1$ and $N_{IMB\text{-}thou} \geqq 2$" is obtained to be 0.27%.
- It is difficult to claim a discovery, but it is certainly an evidence.

## Details of the calculation

The probability of the chance coincidence is:

$$P = (1-Poi(0|\lambda_{KAM\text{-}thru})) \times (1-Poi(0|\lambda_{KAM\text{-}stop})) \times (1-Poi(0|\lambda_{IMB\text{-}thru})-Poi(1|\lambda_{IMB\text{-}thru})) \times (385/71) \times 4$$

$$= 0.119 \times 0.026 \times 0.040 \times 5.42 \times 4$$

$$= 0.0027$$

$Poi(n|\lambda)=\lambda^n e^{-\lambda}/n!$

x(385/71) : 385 days data was analyzed, and 71 days time window was selected.

x4 : Among 4 event samples, 3 event samples are used. ${}_4C_3=4!/(3!\times(4-3)!)=4$.

# Summary ②

- Upward-going muon events from the direction of SN1987A were searched for using data from Kamiokande-II and IMB.
- From the time window between Aug. 11, 1987 - Oct. 20, 1987, and angular window of $\Delta\theta$=10.0°, 4 upward-going muon candidates were found.
- The probability of the chance coincidence of atmospheric neutrinos is 0.27%.
- It might be the first evidence of high energy neutrinos from a supernova remnant just after the explosion.
- Answers to the following FAQs are prepared to the backup slides

Q1: The definition of the time window is very intentional.

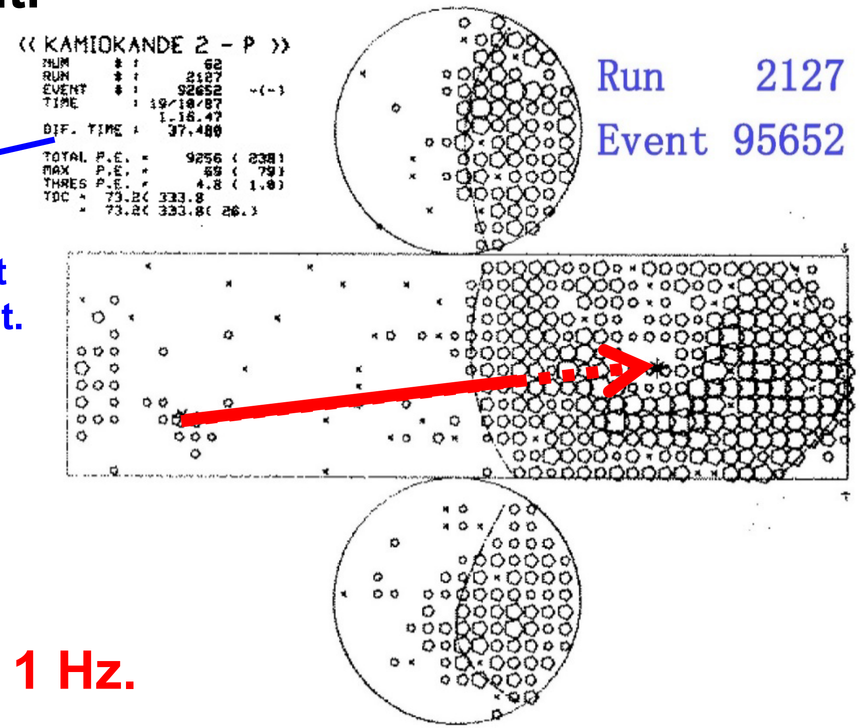
Q2: Is there any feedback to the model of the high energy neutrino generation mechanism, if these upward-going muons are real candidates from SN1987A?

# ③Correlation of two successive events

# Run 2127 Event 92652

- **A curious event was found by chance: Run 2127 – Event 92652. It was a upward stopping muon event.**
  **(It was the first possible upward stopping muon from SN1987A direction. But that is probably irrelevant.)**

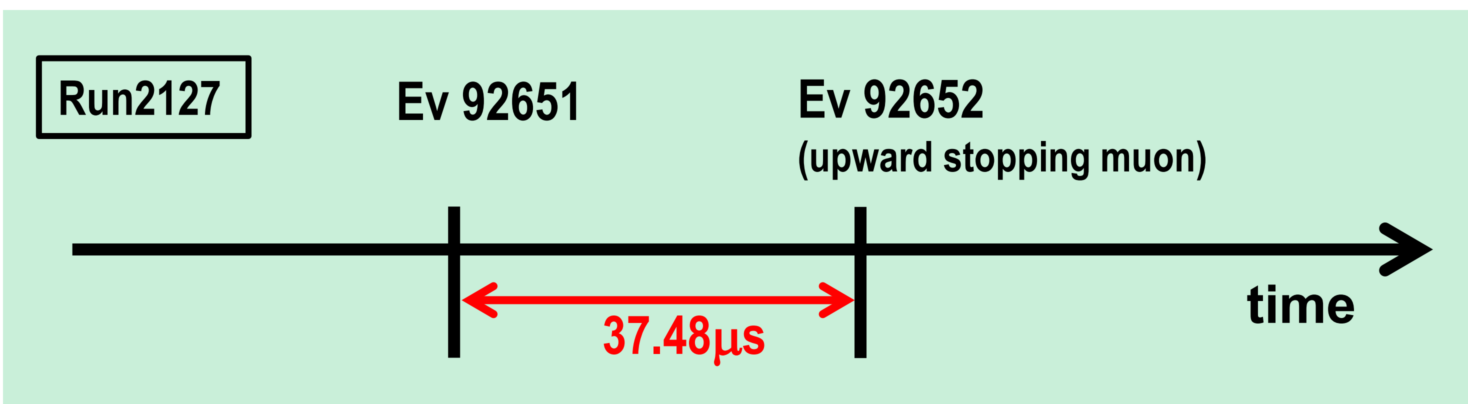

This was pointed out by Nakahata-san first.




- **The reason of the curiosity is that the time interval from the previous event is only**

  $\Delta t = 37.48\mu sec$,

  **although the trigger rate is less than 1 Hz.**



# The preceding event (Run 2127 Event 92651)

- **Unfortunately, the event was recorded in a mine holiday.**
  **The experimental site in the mine could not be accessed.**
  **Because of limited MT capacity, the DAQ was in "holiday mode", in which charge/time information of each PMT were not recorded for most of events.**

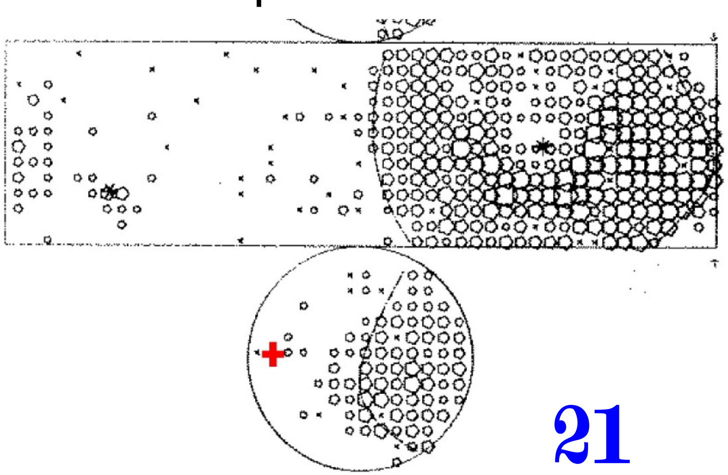
- **Some information of the event were recorded.**

| | |
|---|---|
| Total photoelectron | 15604 p.e. |
| Max Photoelectron | 538 p.e. |
| Max PMT | 906 (bottom) |
| Number of hit PMT | 822 |

- **All of these data well agree with that of a typical cosmic ray muon which pass through the detector with relatively long travel distance in the detector.**

Position of Max PMT
for 92651 is superscribed
on 92652

I am not saying the entrance
position of the 2nd event is close
to the exit position of the 1st event.....



# Is it chance coincidence?

- The chance probability that the time interval from the preceding cosmic ray muon is less than 37.48μs is **P=1.39 x $10^{-5}$** .
- Expected rate of (muon + upward-going muon) in such short time period is **$N_{exp}$=0.00092 event-pairs/year**.
- **Hard to believe that it is a chance coincidence!**
  **It is natural to consider a causal relationship between two events.**
  **If it is the case, it might be an evidence of new physics!**
- What should we do ? → Let's find another (muon + upward-going muon) pairs in short time interval from the data.

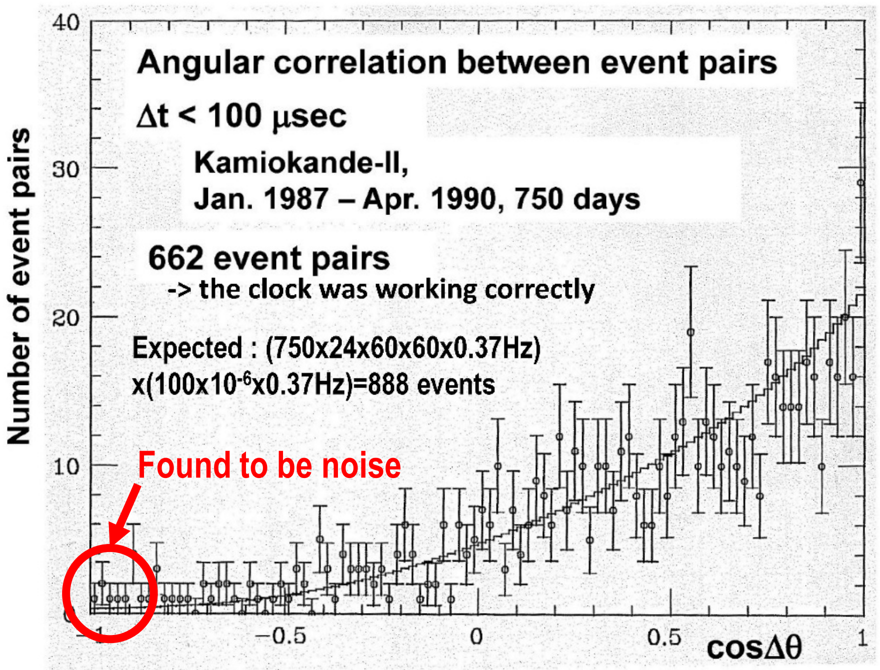
## The details of the calculation

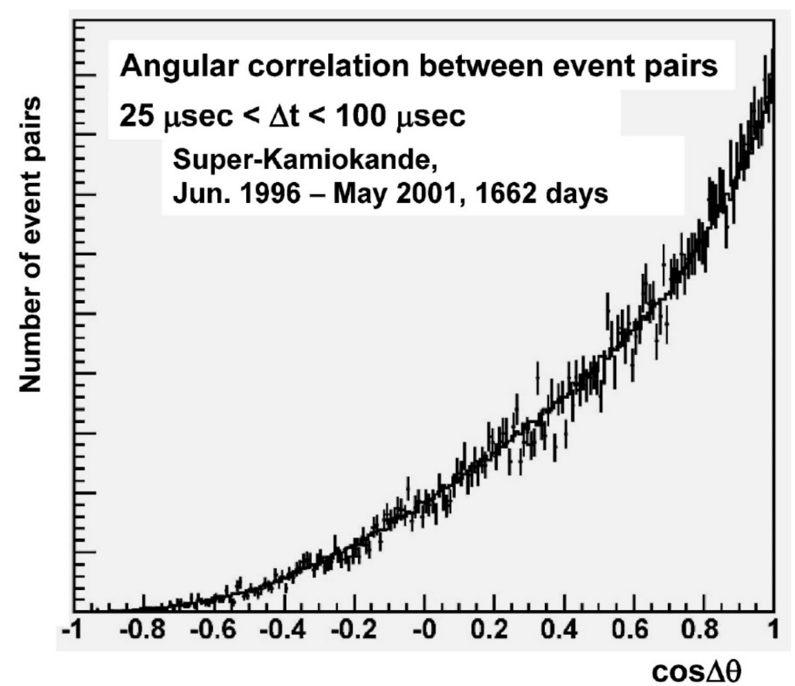
- The cosmic ray muon rate is **~0.37Hz**.
- Number of cosmic ray muon events in 37.48μs is $\lambda$ = 0.37 x 37.48x$10^{-6}$s = **1.39x$10^{-5}$**.
- The probability that more than one muon can be found in 37.48μs is
  P = 1- Poi(0|$\lambda$) = 1-exp(-1.39x$10^{-5}$) = **1.39 x $10^{-5}$** .
- We have **~66 upward-going muon events** in a year. Expected event rate of (cosmic ray muon followed by upward-going muon within 37.48μs) is
  $N_{exp}$=66 x (1.39x$10^{-5}$) = **0.00092 event-pairs/year**.

# Let's find similar event pairs!

① No upward through-going muons in Kamiokande-II data have their preceding events within 10msec.

② Event pairs are selected from a following criteria;
-Both events have total photoelectrons equivalent to muon tracks
-The time difference is less than 100μsec.
Angular correlation of two tracks are plotted.




No clear event pair was found near cosΔθ=-1 bin in Kamiokande-II data and in Super-Kamionade I data. For more details, see backup slides.

# Summary ③

- A curious event pair was happened to be found; a (probably) downward through-going muon followed by an upward stopping muon. The time interval is **37.48μs**.
- Expected number of such event pairs by chance coincidence is **0.00092 event-pairs per year**.
- It is natural to consider a causal relationship between two events. If it is the case, **it might be an evidence of new physics!**
- However, similar event pair cannot be found in 3 years data in Kamiokande-II and 5 years data in Super-Kamiokande-I.

I apologize that I have not analyzed the data for the entire period.
We do not have enough person power to do this kind of very exotic analysis.

# Finally…

- I hope that you enjoyed these results.
- And I will be happy if these results give some hints for your analyses in your on-going experiments.

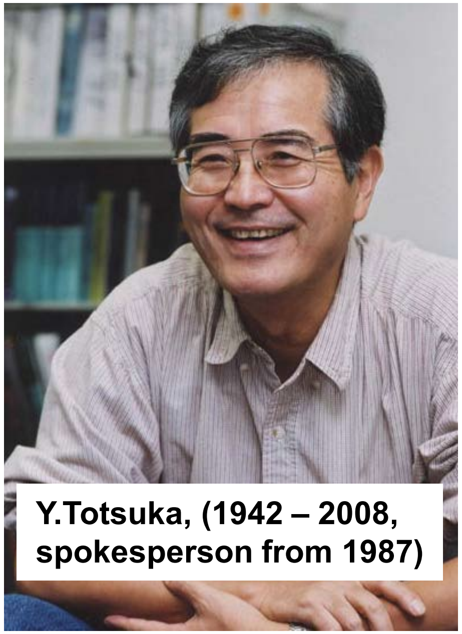
# Thank you !

# BACK UP

# Why now?

- It is more than 30 years from the experiment, and 30 years is reasonably long time for disclosure.
- The Kamiokande collaboration was managed with very primitive rule.
  No collaboration council, no executive committee……..
  If the spokesperson says “Yes”, the result become official.
  It is extremely difficult for me to ask them “Can I make it official?”
- Now both spokespersons passed away.


M. Koshiba, (1926 – 2020, spokesperson until 1987)

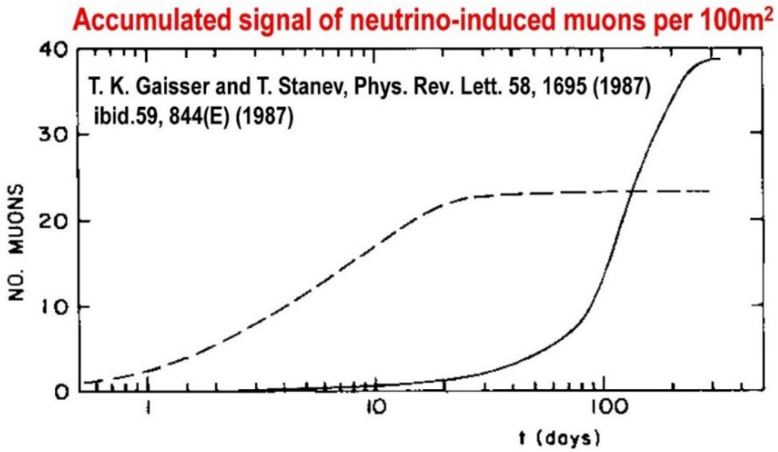

Y.Totsuka, (1942 – 2008, spokesperson from 1987)

# FAQ

**Q1: The definition of the time window is very intentional.**

**A1:**

- **The time structure of the neutrino events is not *a priori* known. We must look for the neutrino period from the data.**
- **To avoid too intentional time window selection, the window is not day by day basis but ~10 days bases, i.e., early (1~10), mid(11~20), and late (21~30 or 31) of the months.**
- **The "trial factor" is properly considered in the calculation of the probability.**




- **The time structure well agree with the theoretical expectation.**
- **The probability of the chance coincidence was also confirmed by a "fake event" analysis.
For details, see https://doi.org/10.3847/1538-4357/ac4269**

# FAQ(continued)

**Q2: Is there any feedback to the model of the high energy neutrino generation mechanism, if these upward-going muons are real candidates from SN1987A?**

**A2: The characteristics of the candidates are;**

**-Two events are upward stopping muon events**

**-Relatively large angler deviations from SN1987A**

**They suggests that the energy of the parent neutrinos might be 10~100 GeV. It is much lower than the neutrino energy predicted by the present theoretical models.**

# Details about the Kamiokande-II event clock

- The interval of the event time played a critical role in the "Correlation of two successive events" analysis.
- The trigger time information from electronics is recorded in event by event basis. It is a time clock, and one count corresponds to 20 nsec. This time information is combined with the DAQ computer clock, and full time information can be obtained with 20 nsec accuracy.
- This time information is useful to study "stopping muon and Michel electron" or "cosmic ray muons and their spallation products".
- From the number of enrties in the left plot of the slide 23, it is verified that the event clock worked correctly.

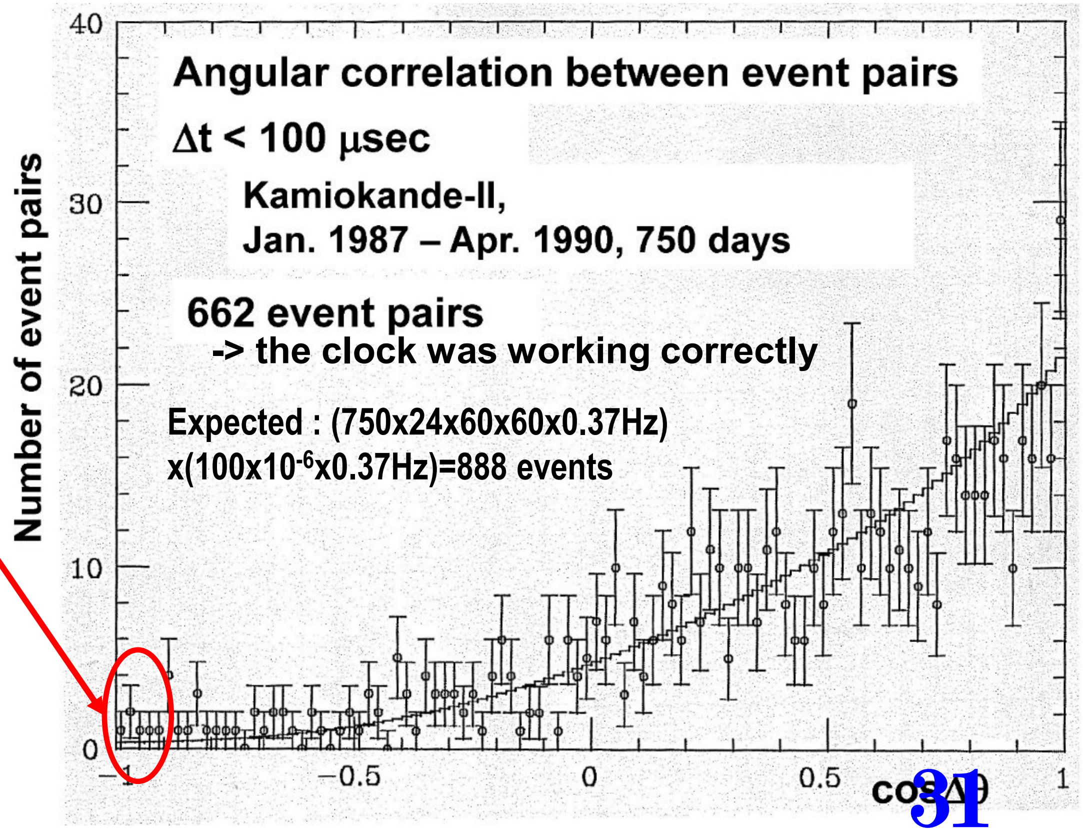
# Kamiokande-II analysis

- (Analysis-1)No upward through-going muon candidates have their preceding events within 10msec.
- (Analysis-2)Event pairs are selected from a following criteria;
  -Both events have total photoelectrons larger than 3000p.e, which is ~1GeV equivalent and corresponding to 5 meter track of muon.
  -The time difference is less than 100μsec.
  Events are reconstructed, and the angular correlation was examined.

In cosΔθ < -0.9, 6 event pairs were found. However, the all first events have large energy deposit in the detector by interactions, and the second events are fake events generated by ringing of the electronics within 10μsec.

Oops! I should have made a plot for 10μsec < Δt < 100μsec, and we should have kept an event view of the interactions!

**No candidates were found!**



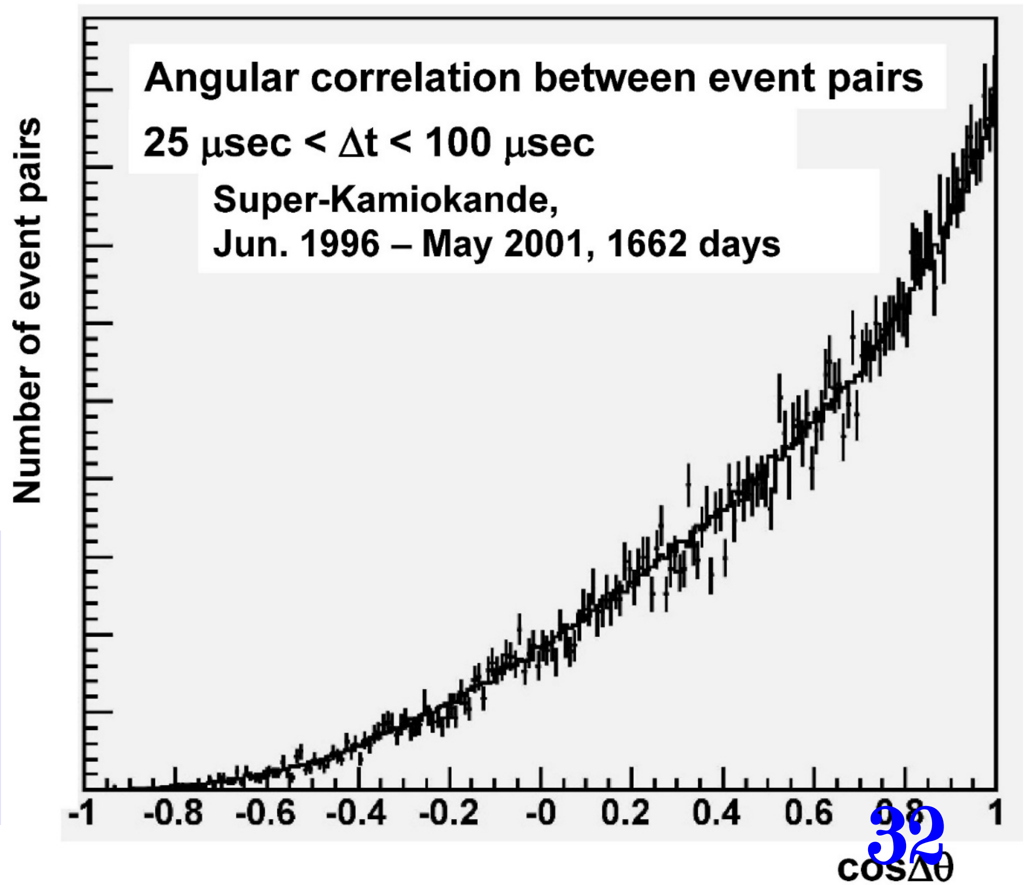
# Super-Kamiokande analysis

- A total of 2.54 x $10^8$ cosmic-ray muon track data were accumulated in Super-Kamiokande-I, when the anisotropy of primary cosmic rays in the celestial coordinate was analyzed.

Observation of the anisotropy of 10 TeV primary cosmic ray nuclei flux with the Super-Kamiokande-I detector, G.Guillian et al., Phys.Rev.D 75,062003(2007)

- I asked G.Guillian to make similar plot using the SK data. (Thank you, Gene and Prof. John G. Learned!)
- We could not find any events near cosΔθ=-1.

Any Super-Kamiokande data must not be shown without collaboration agreement. However, please accept my quite poor excuse that this plot is not “data” because the labels for vertical axis are deleted.



# END

# Extra slide about further details

## Short abstract

Three new topics from old Kamiokande-II experiment are presented. They are seven second gap during SN1987A neutrino burst, high energy neutrino from SN1987A, and abnormal time gap between upward stopping muon and preceding cosmic ray muon.

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## Key-words

"Kamiokande" "SN1987A" "seven second gap" "high energy neutrino from supernova remnant“ "IMB" "cosmic ray muon" "exotic"

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