Global Focus on Knowledge 2005
Science of Matter

Elementary Particle and Universe

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2005-10-17
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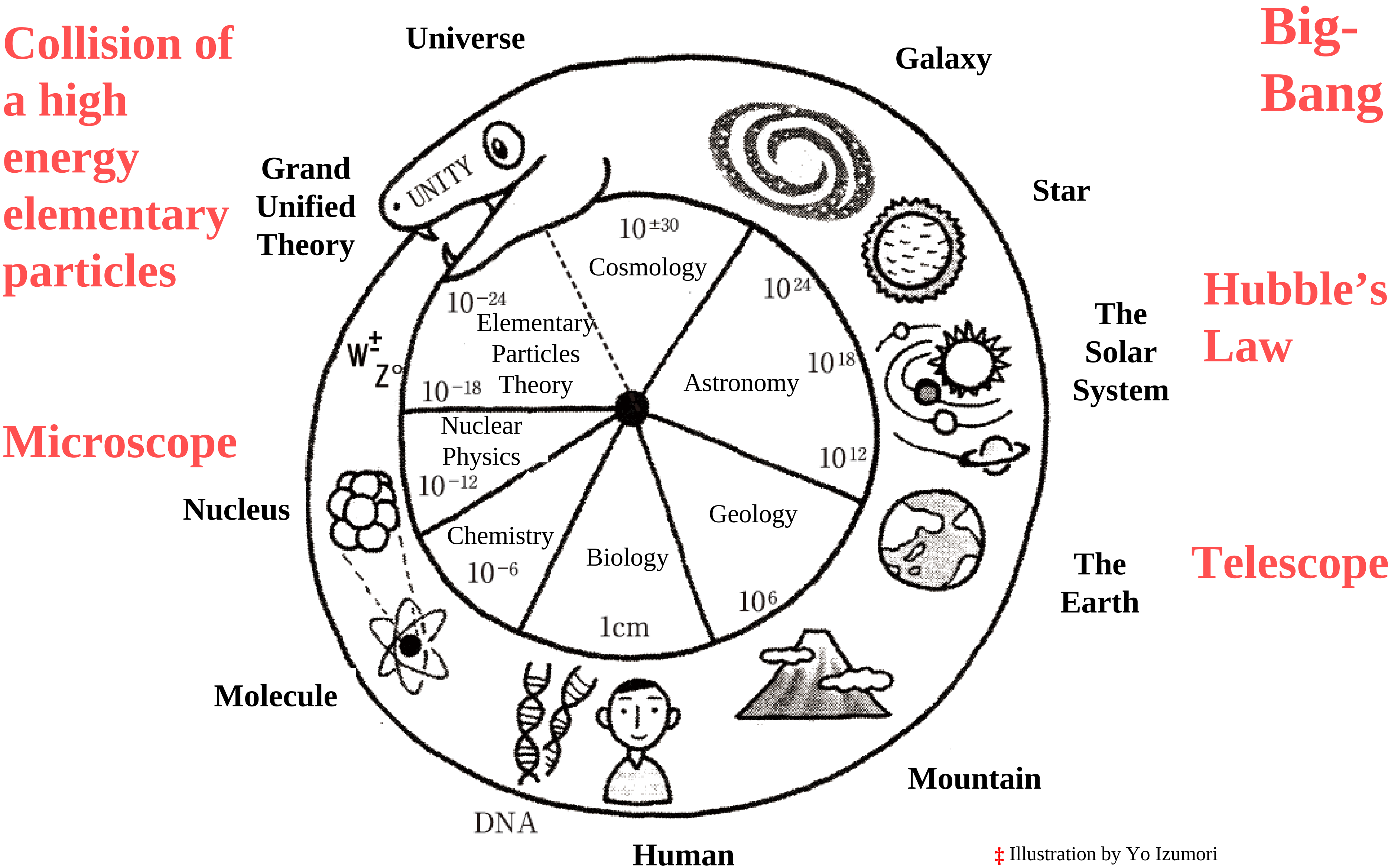
The Origin of Matter

- The Creation
- About a half century ago, G.Gamov assumed the primordial matter in the universe, which he called ylem, consisted entirely of a hot plasma of neutrons.
- During the Big Bang, all the known elementary particles are created along with their antiparticles in an incredibly high temperature and density. However, a mechanism of how roughly a billionth of elementary particles survived still remains to be unknown.

After that,

- 1) Remaining elementary particles combined together to form protons and neutrons. The protons and neutrons then combined to form deuteron, and its nuclei produced helium and a tiny trace of lithium.
- 2) Creation of the heavier atomic nuclei did not take place until the emergence of stars. For a large star, its core generates high pressure and huge temperature, igniting the nuclear fusion reaction that continues to a point in which resulting output of chemical element is iron.
- 3) The supernova created heavier elements beyond iron, and the heavier nuclei absorbed yet more neutrons thereby forming all the heavier elements including radioactive ones such as uranium. This explosion scattered those new elements into space and later condensed into stars. The stars (the earth and the sun) that emerged after this supernova explosion incorporate all the known elements.



「ものの大きさ—自然の階層・宇宙の階層 (UP Physics)」 Yasushi Suto, University of Tokyo Press, figure 6.1 , pp.142.

Comparative Investigation of Elementary Particle

- An elementary particle contains three generations of sixteen members in each group. Take a look at the table of the particle generations in the next screen.
- They also have corresponding antiparticles thus, the total numbers of elementary particles amount to be as great as ninety six all together, and as a matter of fact, physicists has not yet figured out what to do with such great numbers of particles.

u^L, u^L, u^L, c^L, c^L, c^L, t^L, t^L, t^L,

d^L, d^L, d^L, s^L, s^L, s^L, b^L, b^L, b^L,

e^L μ^L τ^L

$\nu_e{}^L$ $\nu_\mu{}^L$ $\nu_\tau{}^L$

u^R, u^R, u^R, c^R, c^R, c^R, t^R, t^R, t^R,

d^R, d^R, d^R, s^R, s^R, s^R, b^R, b^R, b^R,

e^R μ^P τ^R

$\nu_e{}^R$ $\nu_\mu{}^R$ $\nu_\tau{}^R$

First genertion Second generation Third generation

e-Family μ-Family τ-Family

There are four fundamental types of forces: strong, weak, gravity and electromagnetism. Four particles are associated to mediate the accompanying forces respectively.

Eight types of gluons: carriers of the strong forces.
When a quark emits or absorbs a gluon, its color changes: **g**.

The weak force is mediated by $\mathbf{Z}^0$ and $\mathbf{W}^{+-}$.

A mediator of the gravitational force is named graviton.

Photon is the carrier particle of the electromagnetic force: γ.

Electrically Neutral Elementary Particles

- Previous figure shows that there are two states of neutrinos in each generation: left- and right-handed.

- Neutrinos are electrically neutral, therefore extremely difficult to detect.

- Do they really exist?
- What is the importance of neutrinos?

W.Pauli

Introduction of neutrino

W.Pauli, Letter to L.Meitner and her colleagues (letter open to the participants of the conference in Tubingen) (1930).

He proposed in 1930 the existence of a very low or zero mass neutrino that is electrically neutral and intrinsic angular momentum ½, to save the laws of conservation of energy, momentum and angular momentum, which were under threat from the observations of beta decay in radioactive nucleus.

Majorana Neutrino

http://www-news.uchicago.edu/

Ettore Majorana
Nuovo Cim. 14 (1937) 171-184.

He pointed out the possibility of a symmetry property of neutrino.

Neutrino=Anti-neutrino

Physicists still do not know whether the neutrino is of the Majorana type or the Dirac type.

The experiment involves with the double beta decay experiment.

Reines and Cowan's Neutrino Detector

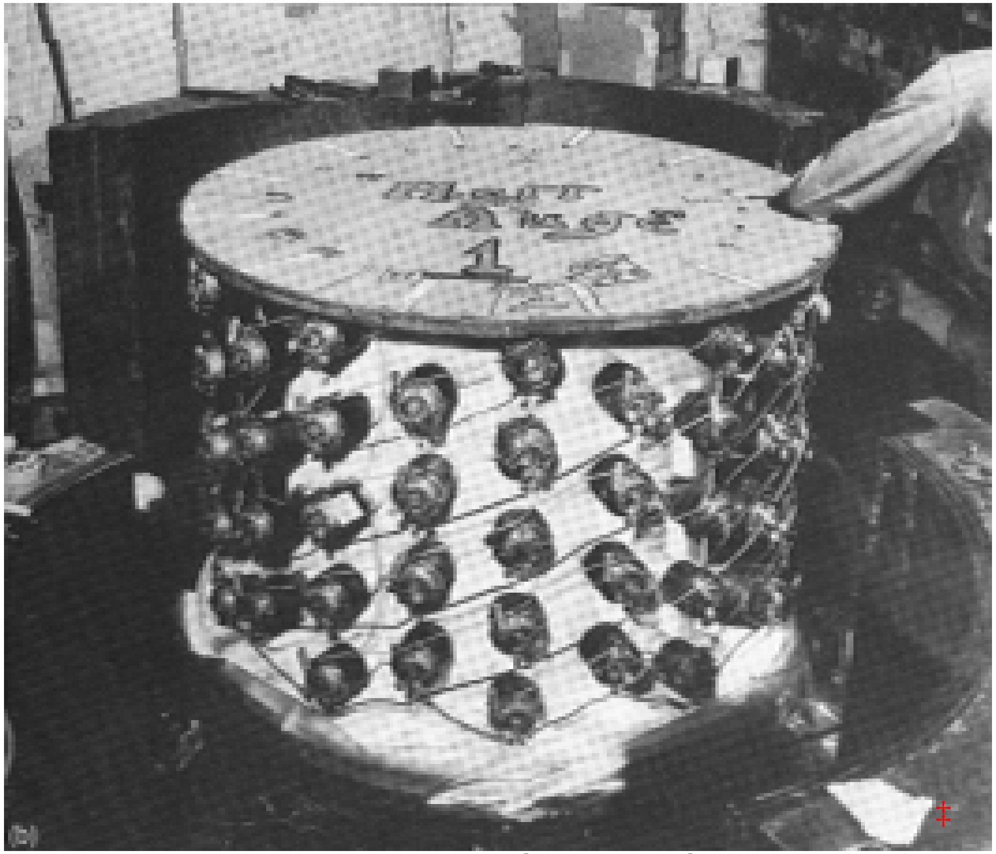
Observation of anti-ne from the nuclear reactor.

F.Reines and C.L.Cowan, Phys. Rev. 92 (1953) 830.

F.Reines and C.L.Cowan, Phys. Rev. 113 (1959) 273.

They detected
the anti electron-neutrino
from the nuclear reactor.
3 recorded events

F.Reines and C.L.Cowan, Phys. Rev. 92 (1953) 830.



F.Reines and C.L.Cowan, Phys. Rev. 113 (1959) 273.

Maki, Nakagawa and Sakata

Possibility of neutrino oscillation suggested in very early period of time.

Z.Maki, M.Nakagawa, and S.Sakata, Prog. Theo. Phys. 28 (1962) 870.

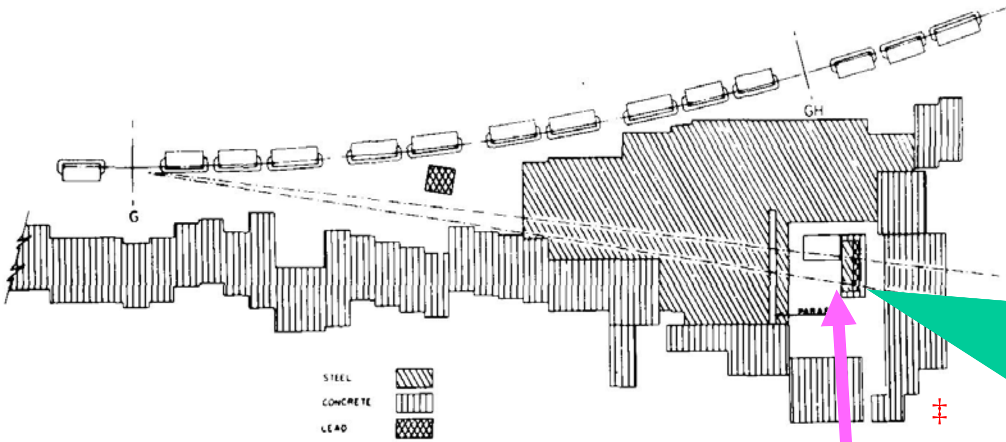
Source. "© Graduate School of Science, Nagoya University"

S.Sakata

http://www2.yukawa.kyoto-u.ac.jp/~sg/award_s/medal02.html

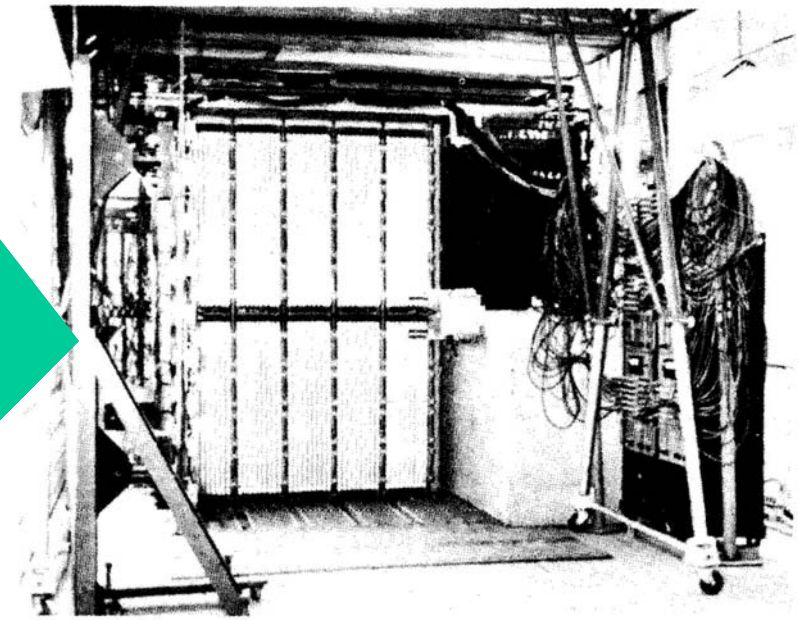
Z.Maki

Discovery of Muon Neutrino ν_μ



Neutrino detector

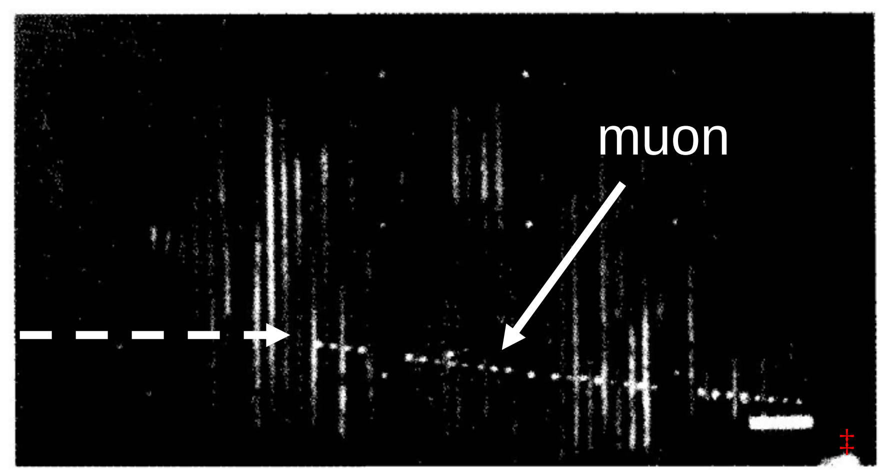
G.Danby et al., Phys. Rev. Lett. 9 (1962) 36.



Observation of ν_μ

G.Danby et al., Phys. Rev. Lett. 9 (1962) 36.

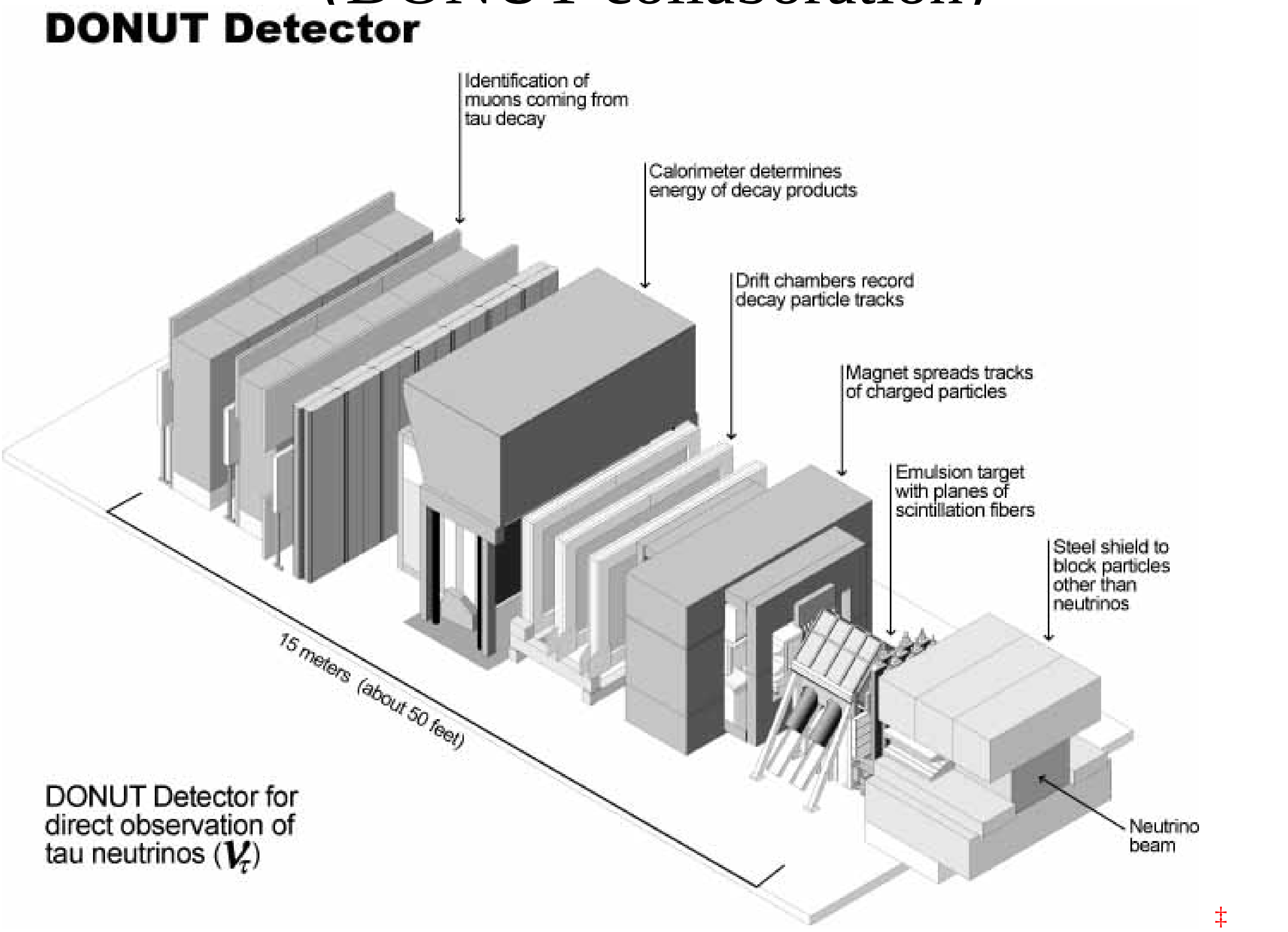
ν



G.Danby et al., Phys. Rev. Lett. 9 (1962) 36.

Observed event

Discovery of Tau Neutrino ν_τ
(DONUT collaboration)



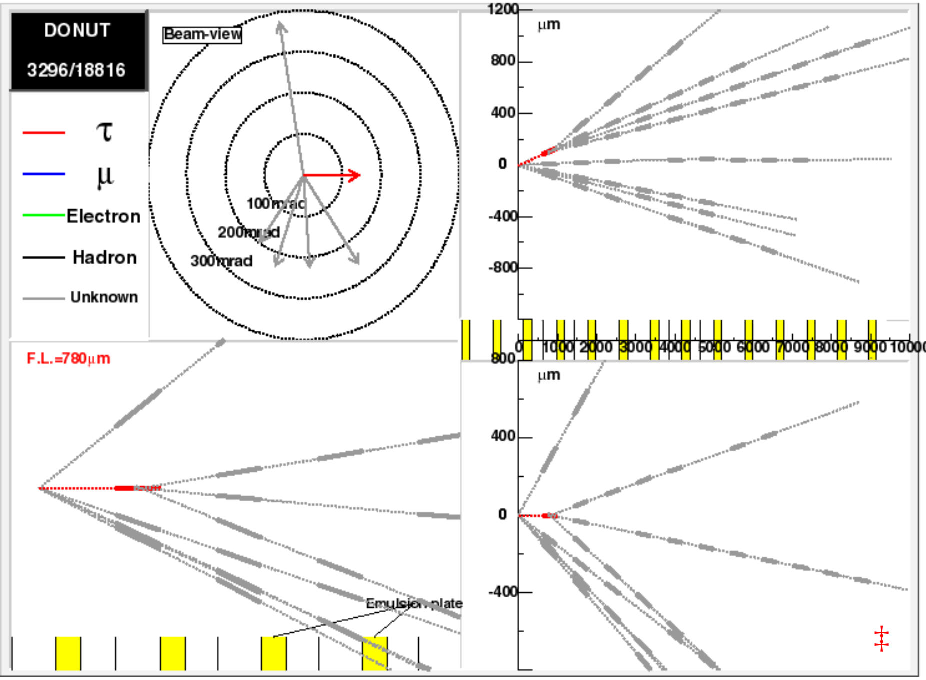
‡

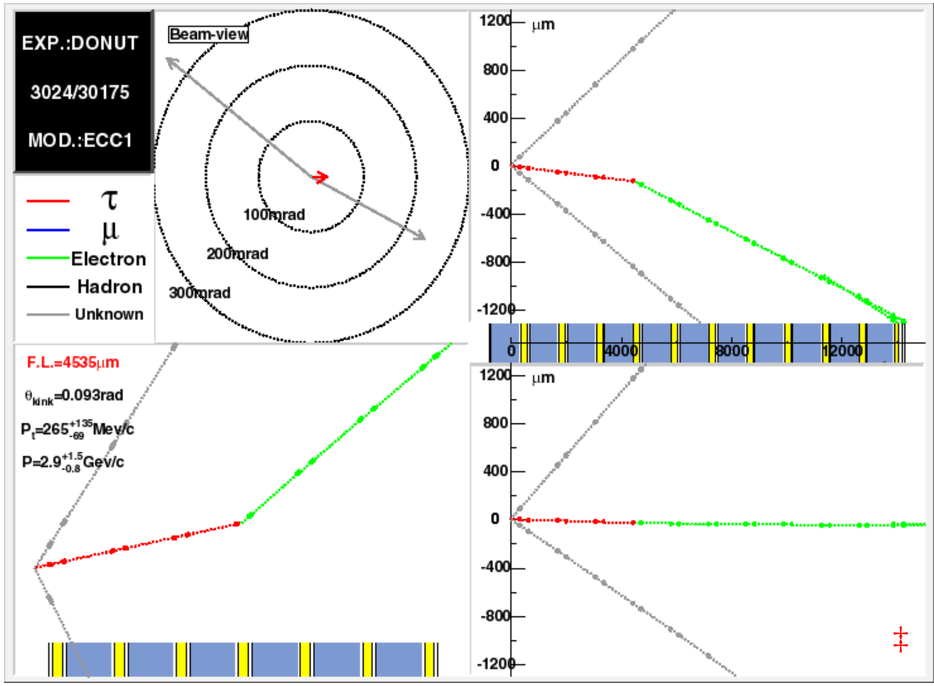
http://www.fnal.gov/pub/inquiring/physics/neutrino/discovery/photos/detector_low.jpg

Two Events of ν_τ

Observation of ν_τ

K.Kodama et al., Phys. Lett. B 504 (2001) 218.





2 examples of ν_τ candidates

3 Known Types of Neutrinos

- Is there any possibility that the additional species of neutrinos exist? The answer is NO.

LEP accelerator very accurately determined the decay width of Z^0 meson, and concluded that there are only three known types of neutrinos.

What is the importance of these neutrinos in astrophysical sources?

What do they help us to probe the universe?

What kind of physical characteristics do neutrinos hold?

The Sun Emit Electron Neutrino (Solar Neutrino)

- In the core of the sun, the nuclear fusion reaction takes place, where it transforms four p into ^4He, implying that there are two neutrinos emitted to each ^4He. The measurements of the energy emitted by the sun per second may allow us to determine how many ^4He are being produced, and further allows us to find how many neutrinos per second are being emitted.

Homestake Solar Neutrino Experiment

When solar electron neutrino is reacted to ^{37}Cl, an electron is emitted and changes into ^{37}Ar.

By detecting this ^{37}Ar, an arrival of solar electron neutrino can be obtained.

Arrival Direction:Unknown

Energy Spectrum:Unknown

Accuracy of Arrival Time:About a Month

http://www.bnl.gov/bnlweb/raydavis/images/hires/CN11-769-67.jpg

R.Davis Jr. at Homestake

Radiochemical Observation of Solar Neutrino

http://www.bnl.gov/bnlweb/raydavis/images/hires/CN10-818-99.jpg

Apparent deficit of solar neutrinos.

Only 1/3 of the expected values were observed.

R.Davis Jr., D.S.Harmer and K.C.Hoffman,

Phys. Rev. Lett. 20 (1968) 1205.

B.T.Cleveland et al.,

Astrophys. J. 496 (1998) 505.

B.Pontecorvo

http://pontecorvo.jinr.ru/

Neutrino oscillation hypothesis

B.Pontecorvo,
Zh. Eksp. Teor. Fiz. 53 (1967) 1717
[Sov. Phys. JETP 26 (1968) 984].

He proposed an idea of neutrino oscillation in order to confirm the experiment by R.Davis.

L.Wolfenstein, A.Yu Smirnov and S.P.Mikheyev

In the medium of high electron density, there is greater oscillation of $\nu_{e.}$
Now that the property of non-zero mass of a neutrino is being confirmed, there is no need for this mechanism.

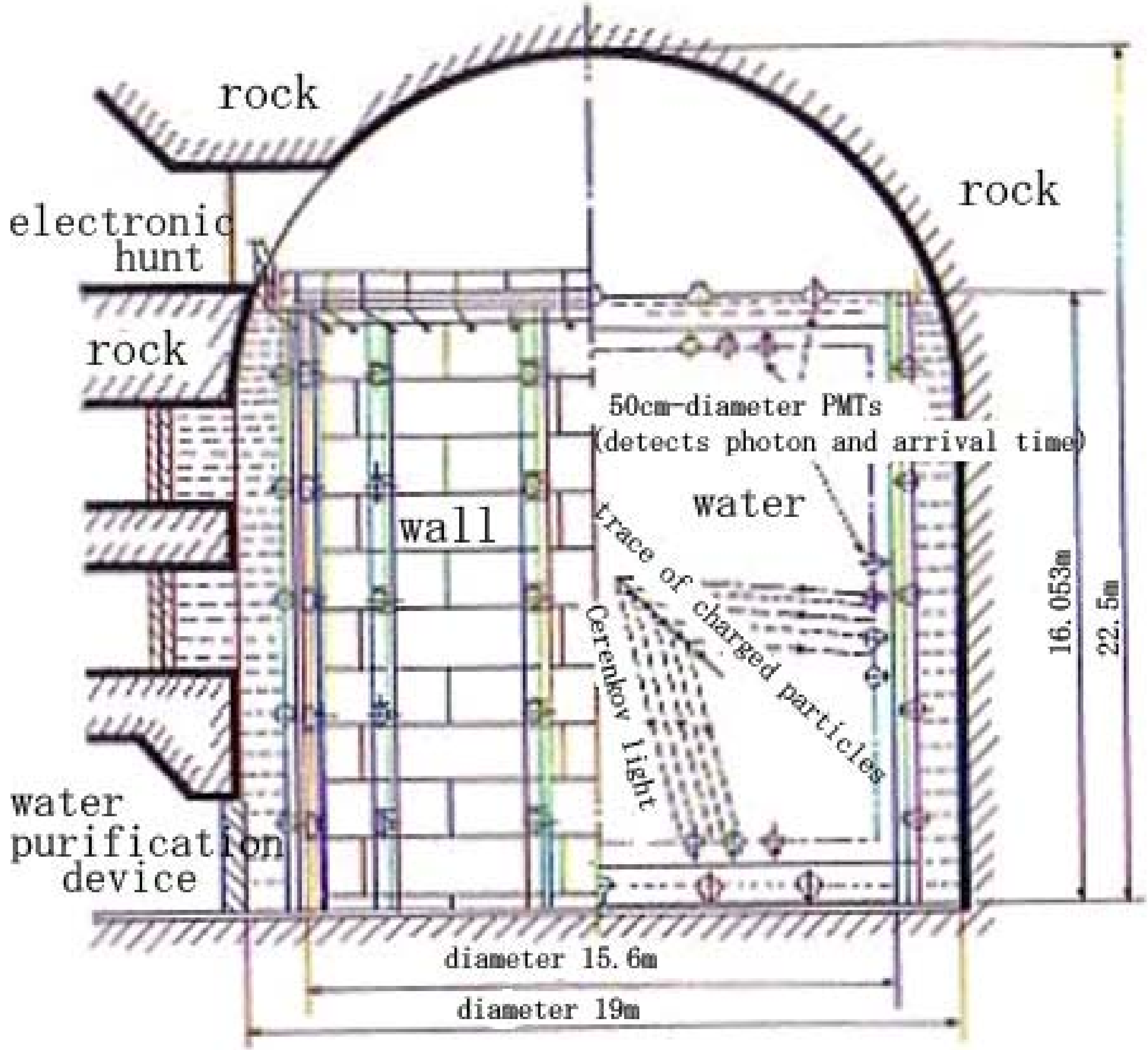
S,P.Mikheyev and A.Yu.Smirnov, Sov. J. Nucl. Phys.42 (1985) 1441.
L.Wolfenstein, Phys. Rev.D 17 (1978) 2369.

http://www.sns.ias.edu/~jnb/Galleries/Some_Solar_Neutrino_Researchers/image014.htm

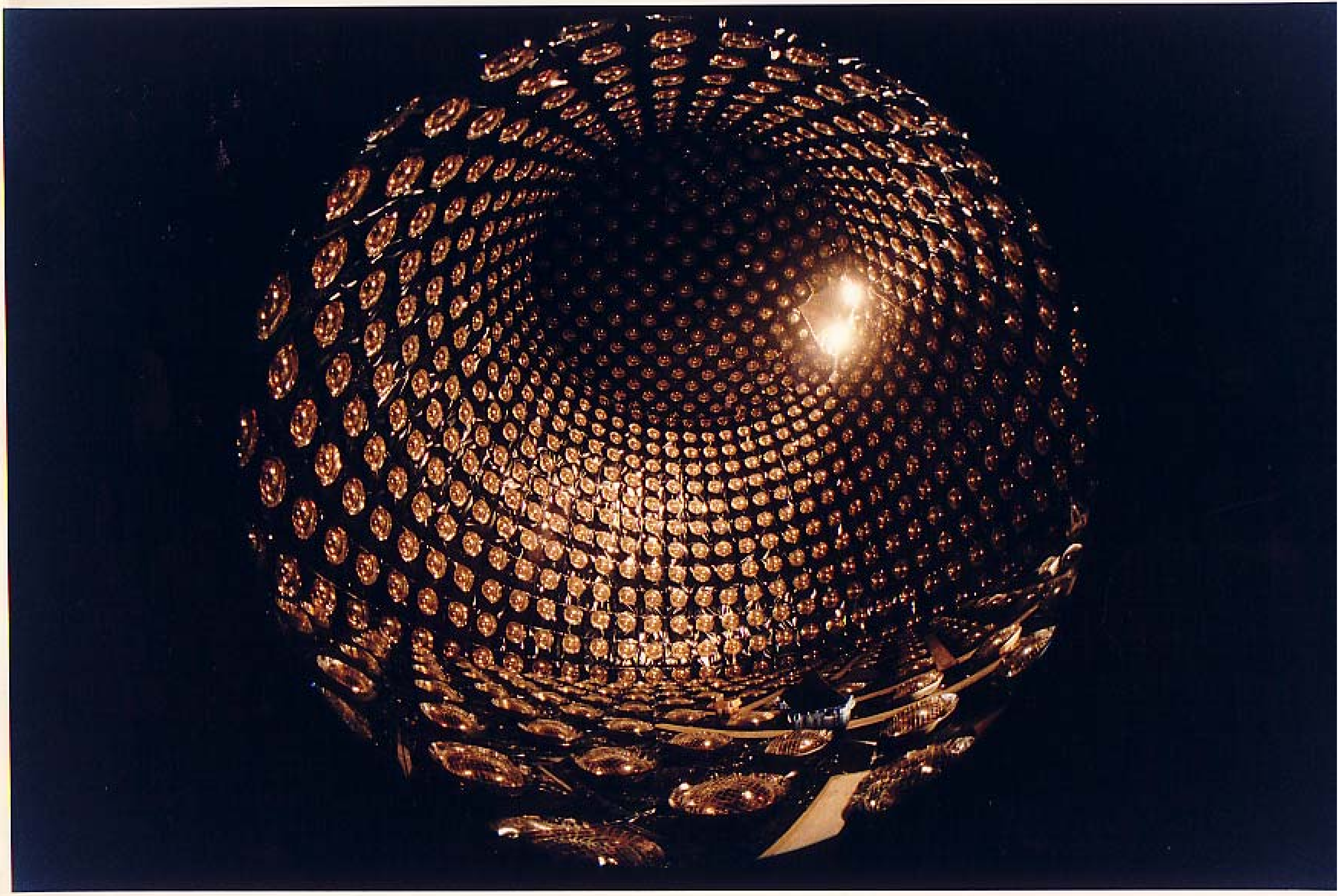
Astrophysical Observations

- Given all the necessary electrical signals being present;

  including the arrival time T, the arrival direction D and the energy spectrum E, the solar neutrinos interact with electrons in water scattering as they collide. The electrons are observed by Cerenkov light they emit.



KamiokaNDE detector located 1km below in Kamioka



The world’s largest photomultiplier tubes equipped by KamiokaNDE were jointly developed by Hamamatsu Photonics Co., using 50cm-diameter PMTs.

Our success in developing KamiokaNDE allowed us to an astrophysical observation of solar neutrinos and the detection of neutrinos from supernova explosion, further led us to a discovery of the neutrino oscillation.

The Early Performance of KamiokaNDE Detector in 1987

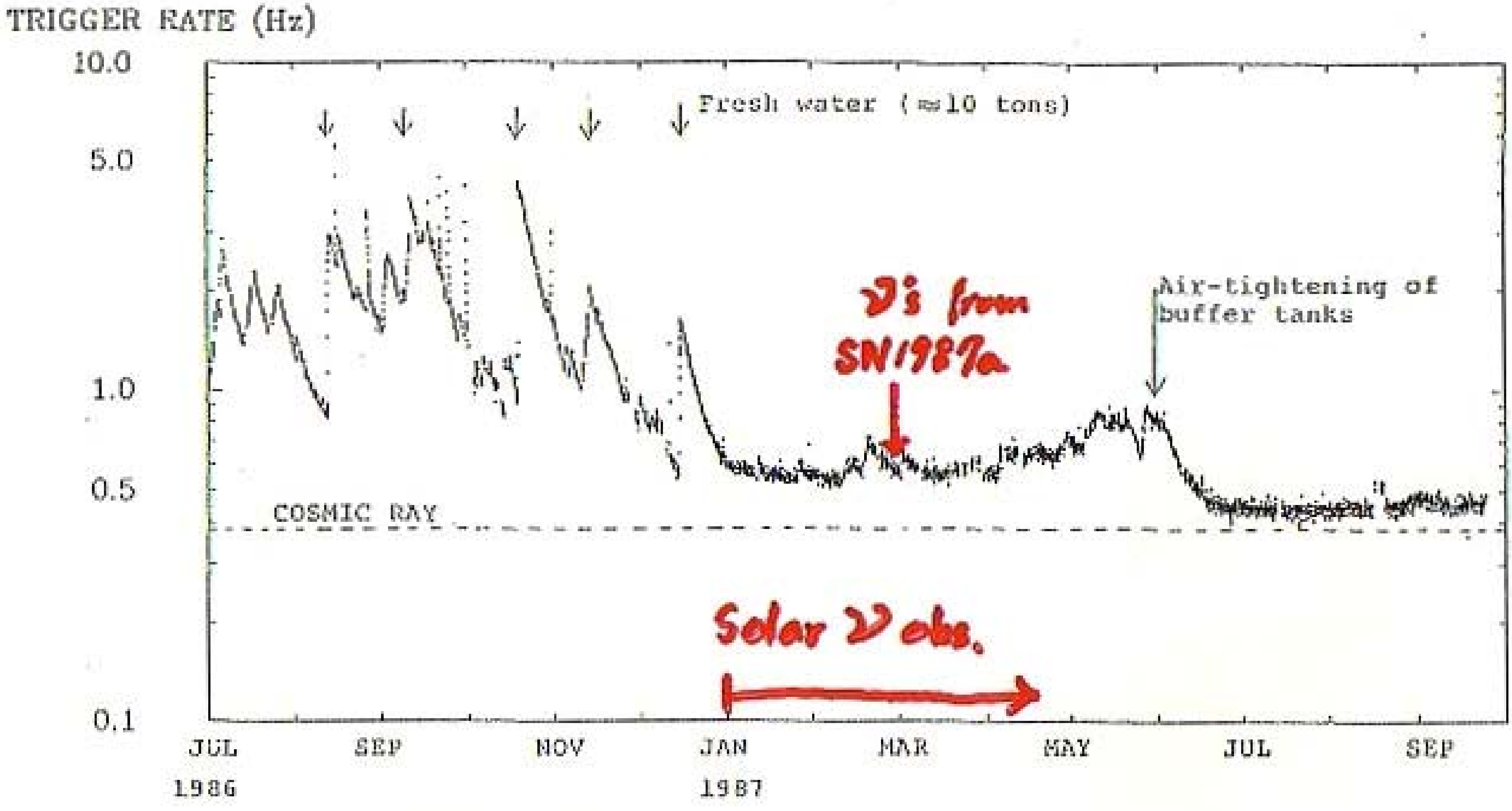


Fig. 3.20. The early performance of the KAM-II detector.

A supernova explosion in the Large Magellantic Cloud 1987A.

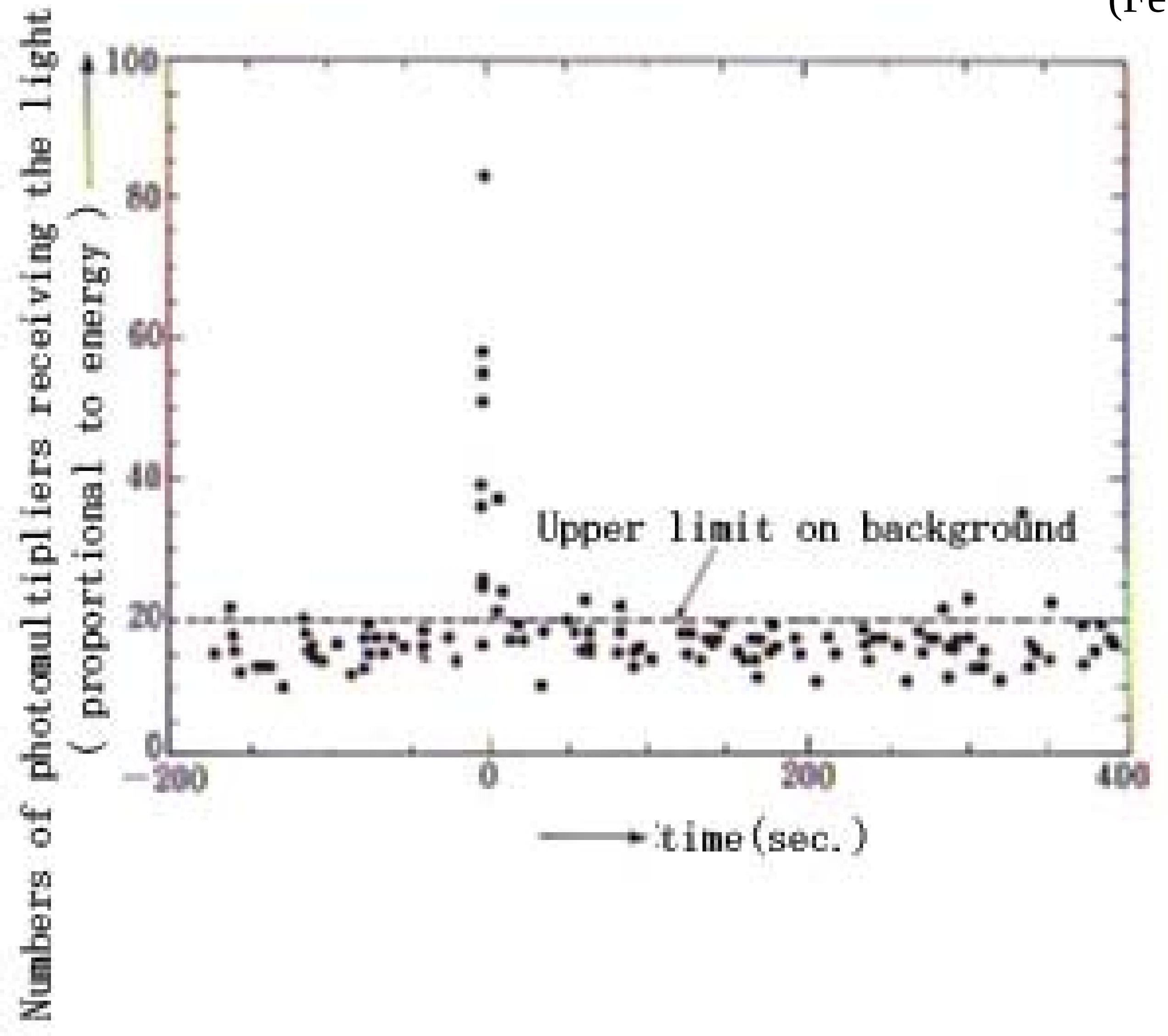
Fig. above shows before the explosion

Fig. below shows after the explosion.

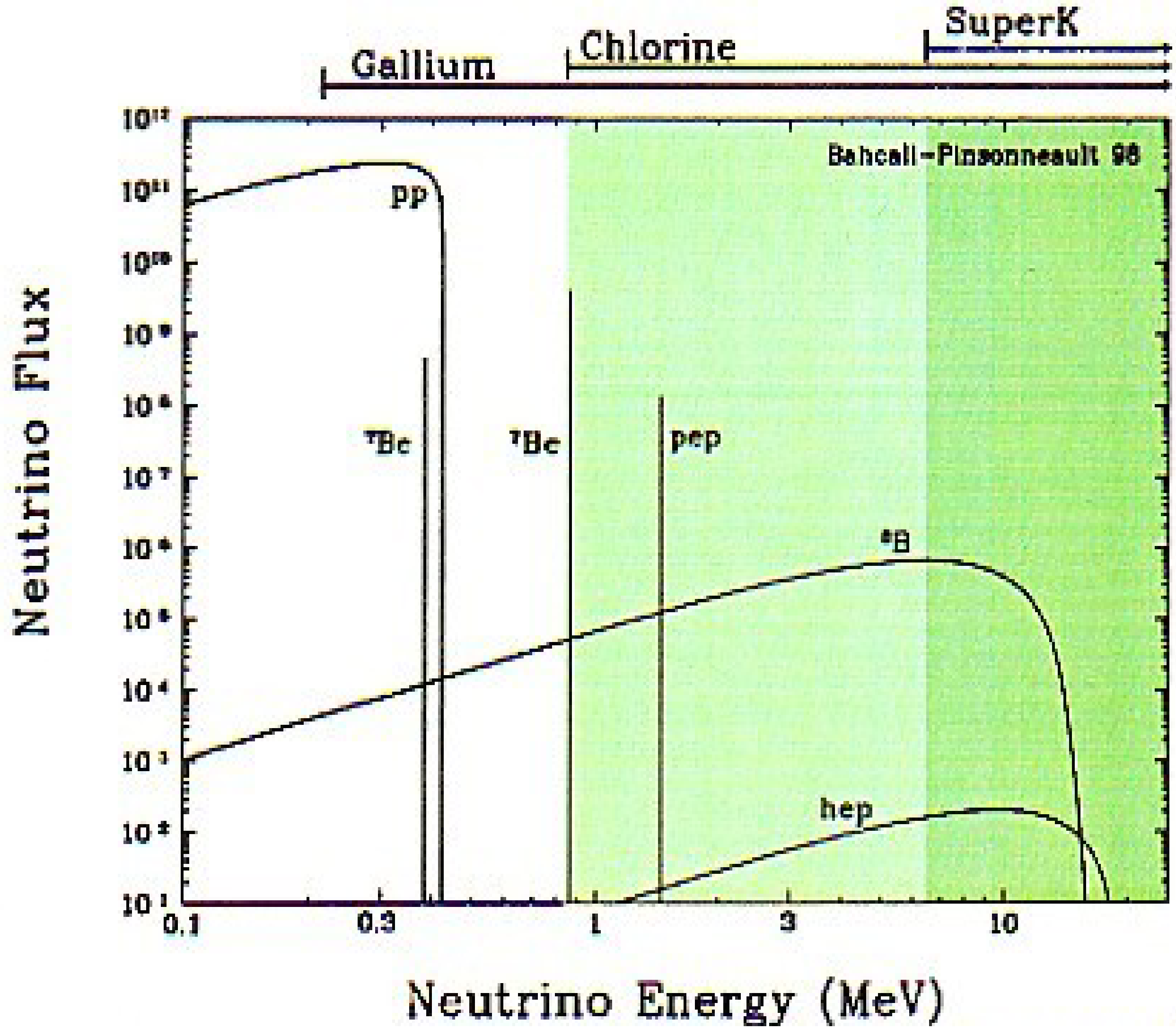
(Anglo-Australian Observatory)

Neutrino Signals at Supernova Explosion

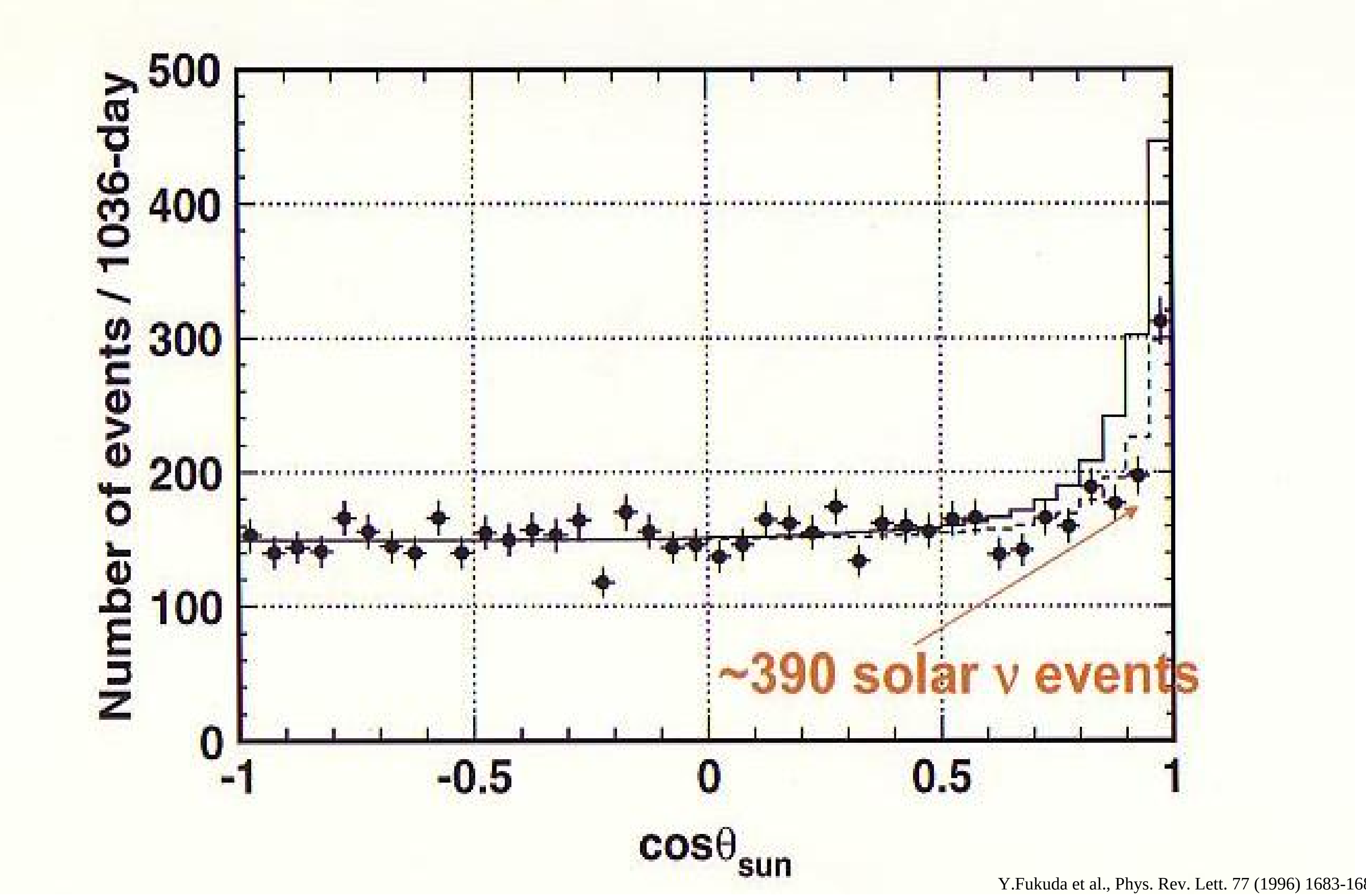
(Feb 23, 1987)



Energy Spectrum of Solar Neutrino Expected From Theory

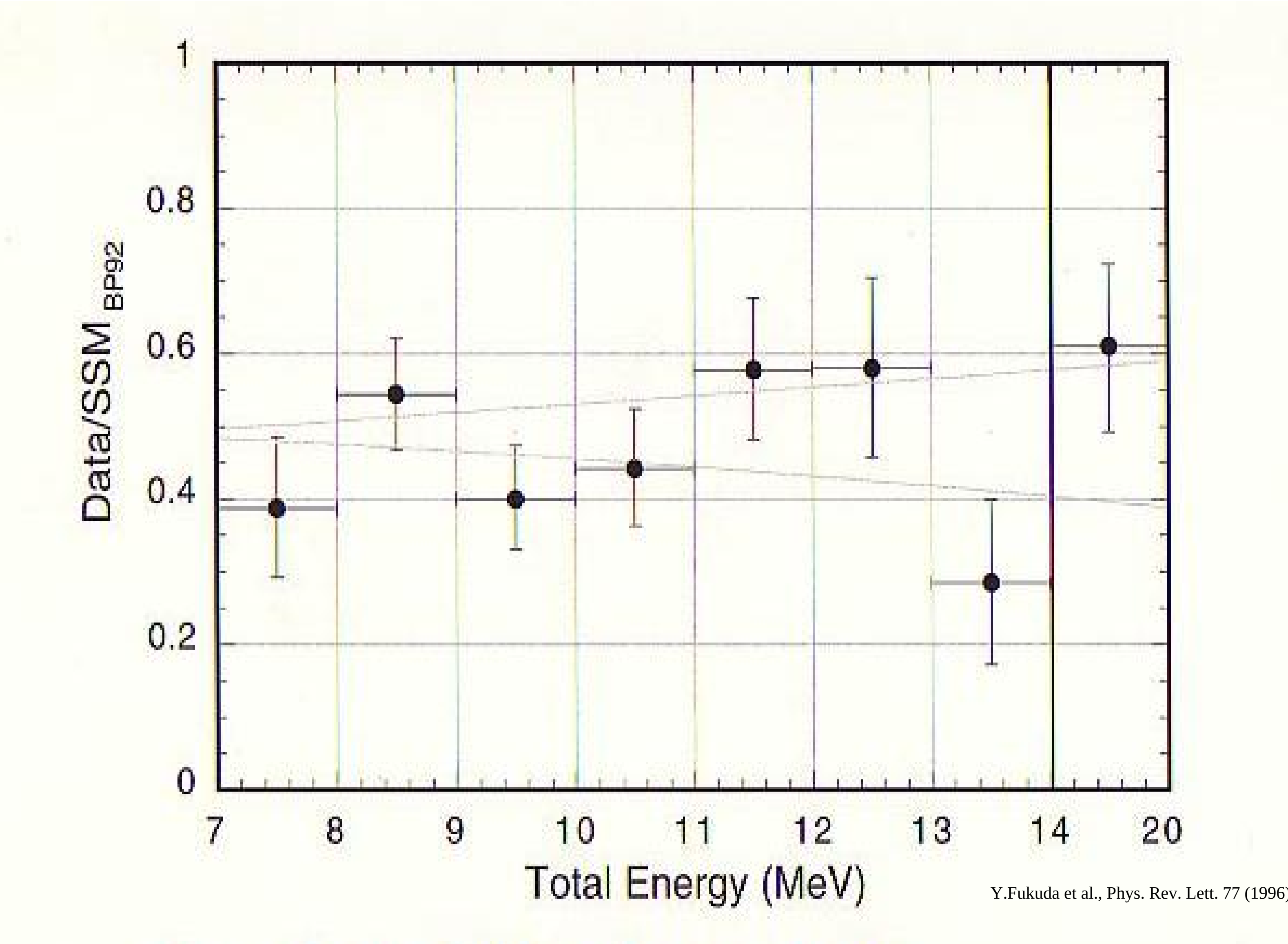


Direction Distribution of Solar Neutrino Measured by KamiokaNDE



Y.Fukuda et al., Phys. Rev. Lett. 77 (1996) 1683-1686

Energy Spectrum of Solar Neutrino Measured by KamiokaNDE



Y.Fukuda et al., Phys. Rev. Lett. 77 (1996) 1683-1686

宇宙

Universe

ニュートリノ

Neutrino

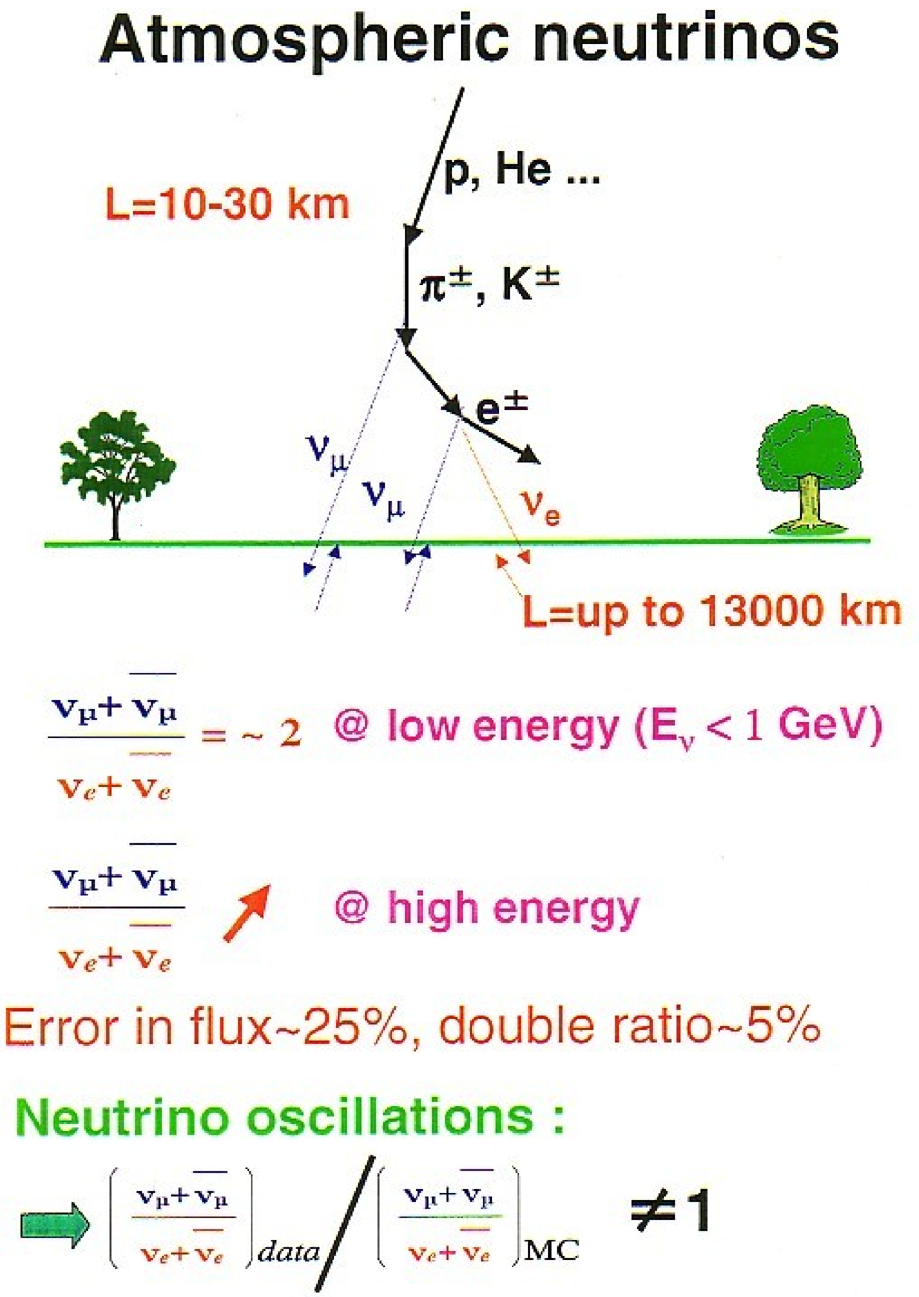
素粒子

Elementary Particle

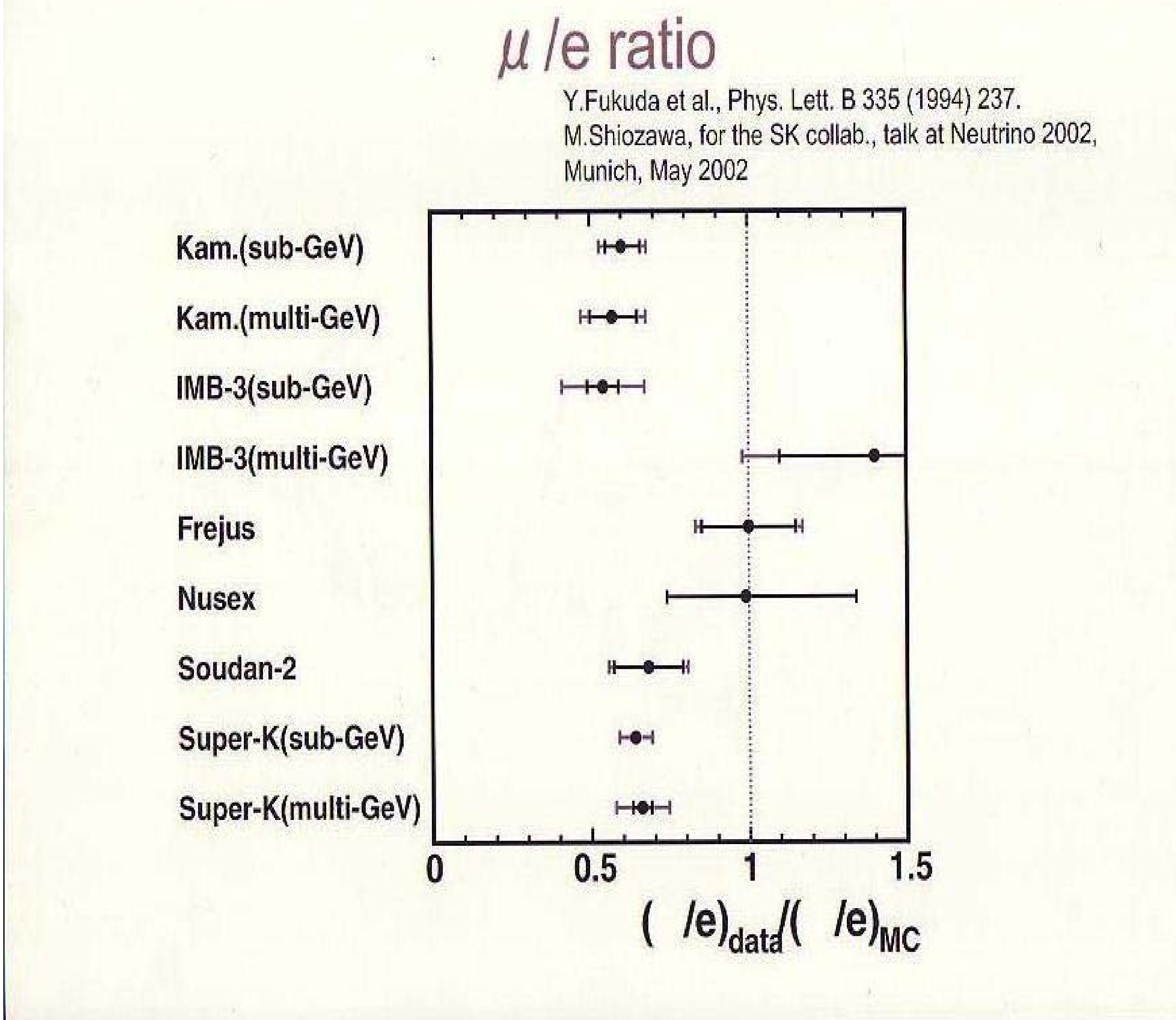
Words I wrote down on the blackboard in the first day of class at University of Tokyo in 1964.

The flux ratio of ν_μ/ν_e is predicted to be greater than 2.

An effect of the traveling distance can be studied by upward-going neutrinos.



The Ratio of Muon Neutrinos in Atmospheric Neutrinos to Electron Neutrinos



Neutrino Oscillation

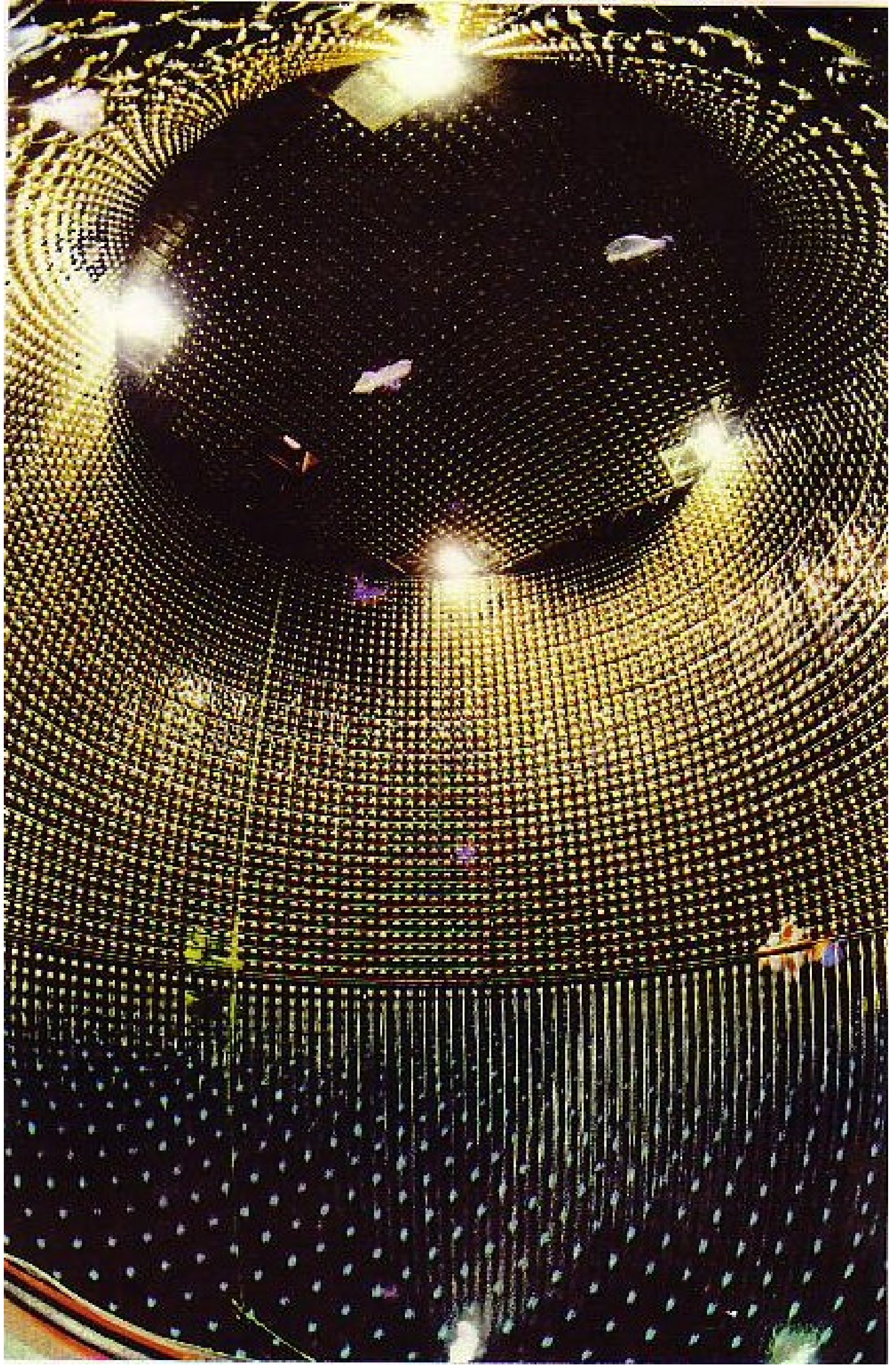
- The discrepancy in the ratio of electron neutrinos ν_e to muon neutrinos ν_μ is observed in atmosphere. KamiokaNDE collaboration confirmed the neutrino oscillation, in which muon neutrinos ν_μ transform into tau neutrinos ν_τ as they travel along the atmosphere. ν_μ

This in itself is an evidence that neutrinos have mass and that mass is different for each type of neutrino.

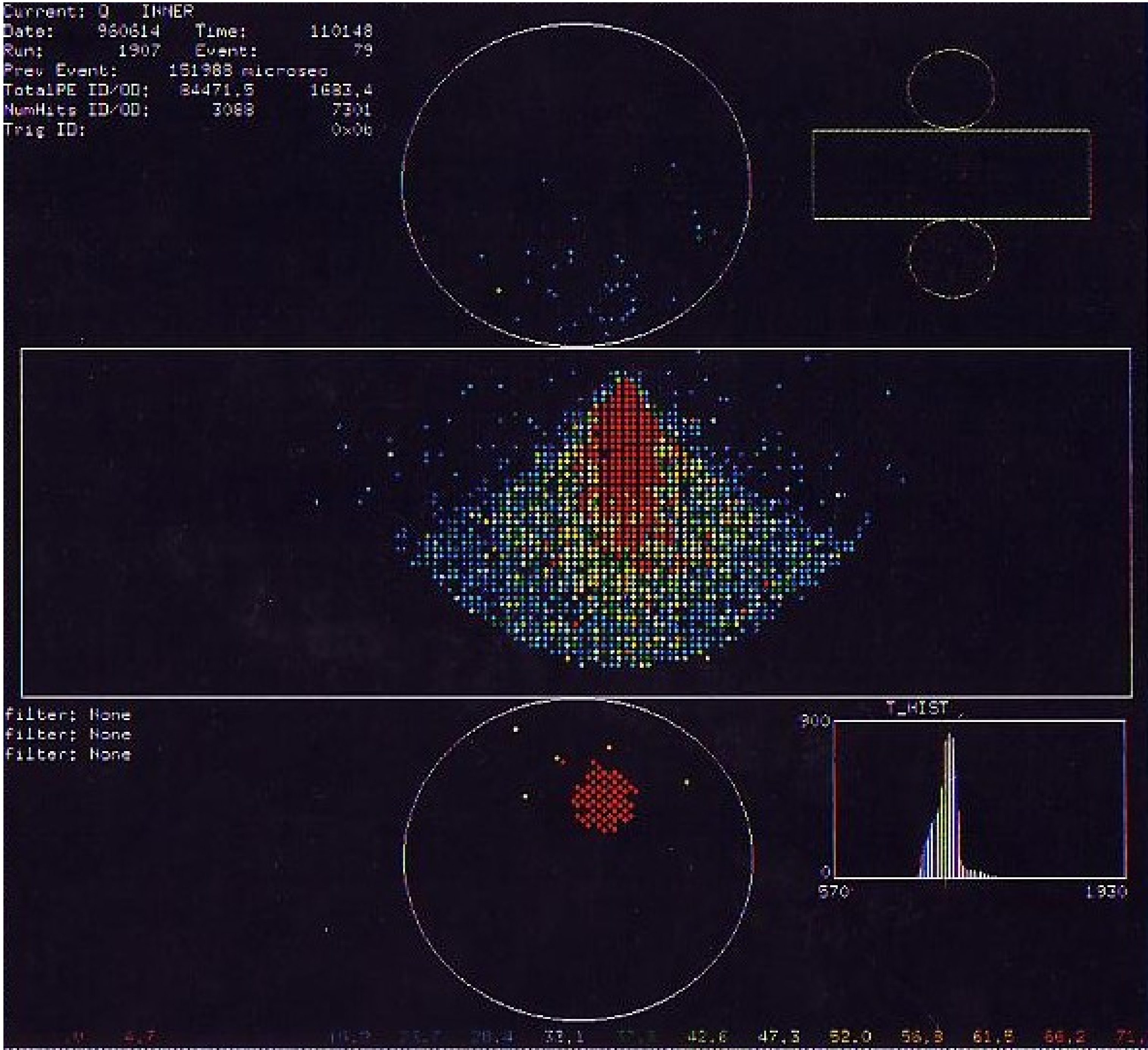
Four Significant Accomplishments of KamiokaNDE

1) The astrophysical observation of solar neutrinos by means of ν_e-e scattering. By astrophysical observation, we mean all necessary information is available; i.e., direction D, time T and the energy spectrum E.
2) The detection of antielectron neutrinos from gravitational collapse of a supernova explosion observed in the Large Magellanic Cloud, supernova 1987A, type II. The observation is approached with the antielectron neutrinos, which characteristically interact with protons **p** and transform into positrons e^+ and neutrons **n.**
3) The discovery of the Atmospheric Neutrino Anomality. Producing a strong evidence for neutrino oscillation to the observed discrepancy in atmospheric ν_μ/ν_e ratio. It confirmed the non-zero neutrino masses, and claimed that muon neutrinos ν_μ oscillate into tau neutrinos ν_τ.
4) Ruled out SU(5) models by the non-observation of proton decay, also excluded SUSY SU(5) models of the Grand Unification Theories by the non-zero masses of neutrinos.

Interior of Super-Kamiokande through fish-eye-lens.

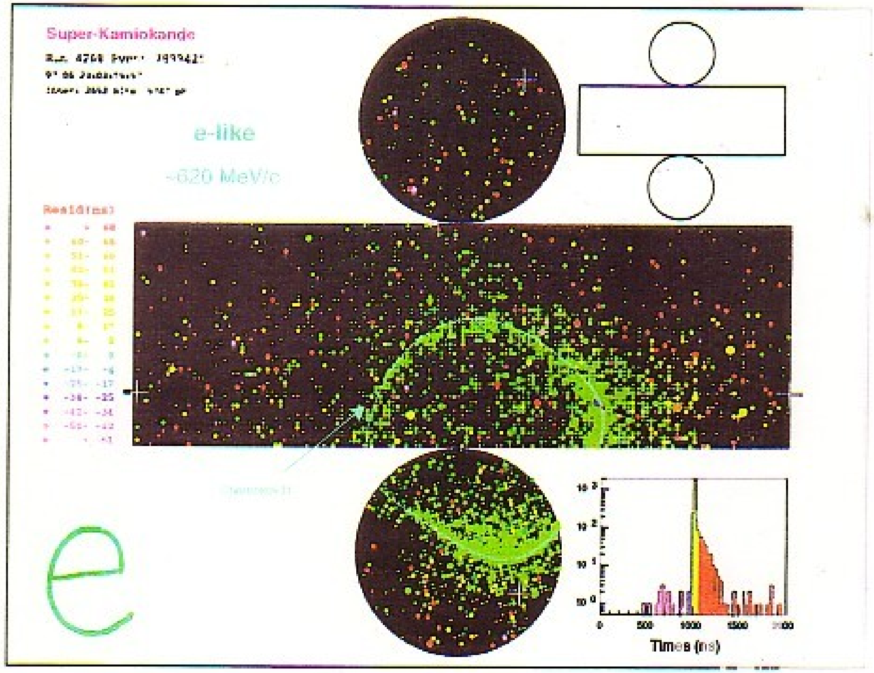


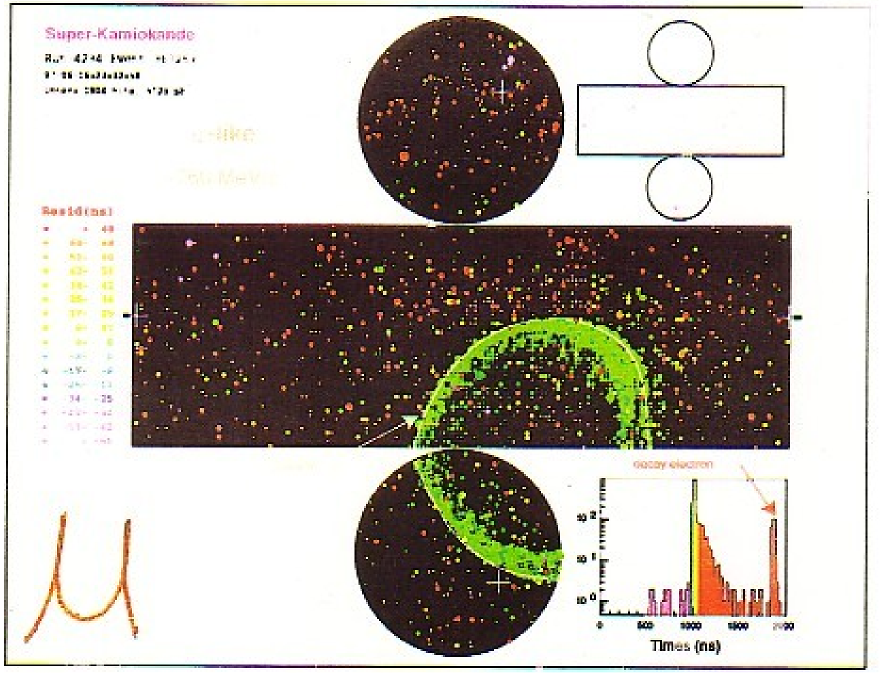
μ Particles reach the bottom faster while the Cerenkov light is still on its way.



Electron event (above)

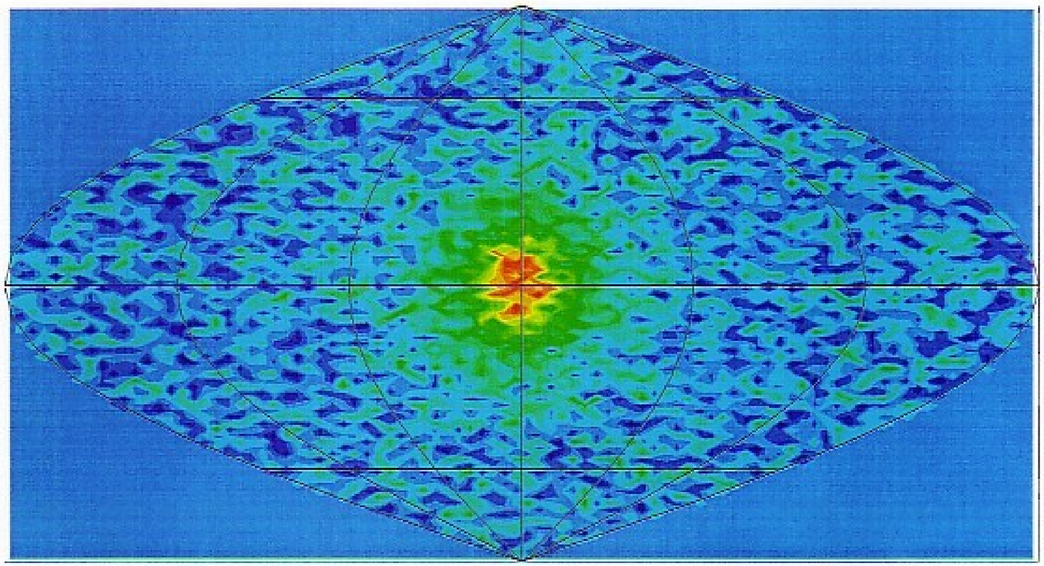
Muon event (below)



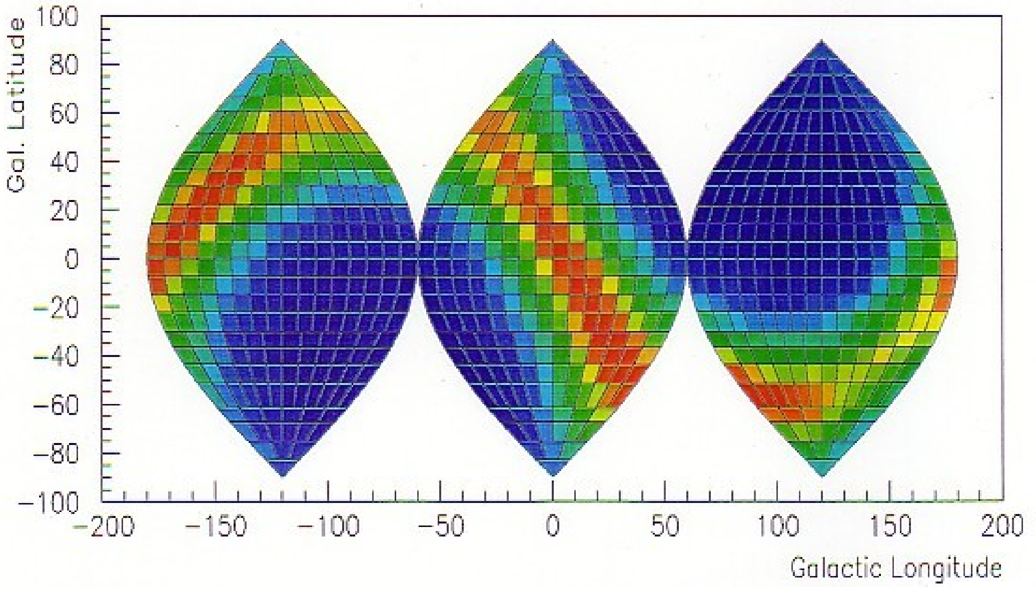


A Solar neutrino graph.

The Sun by Neutrinograph

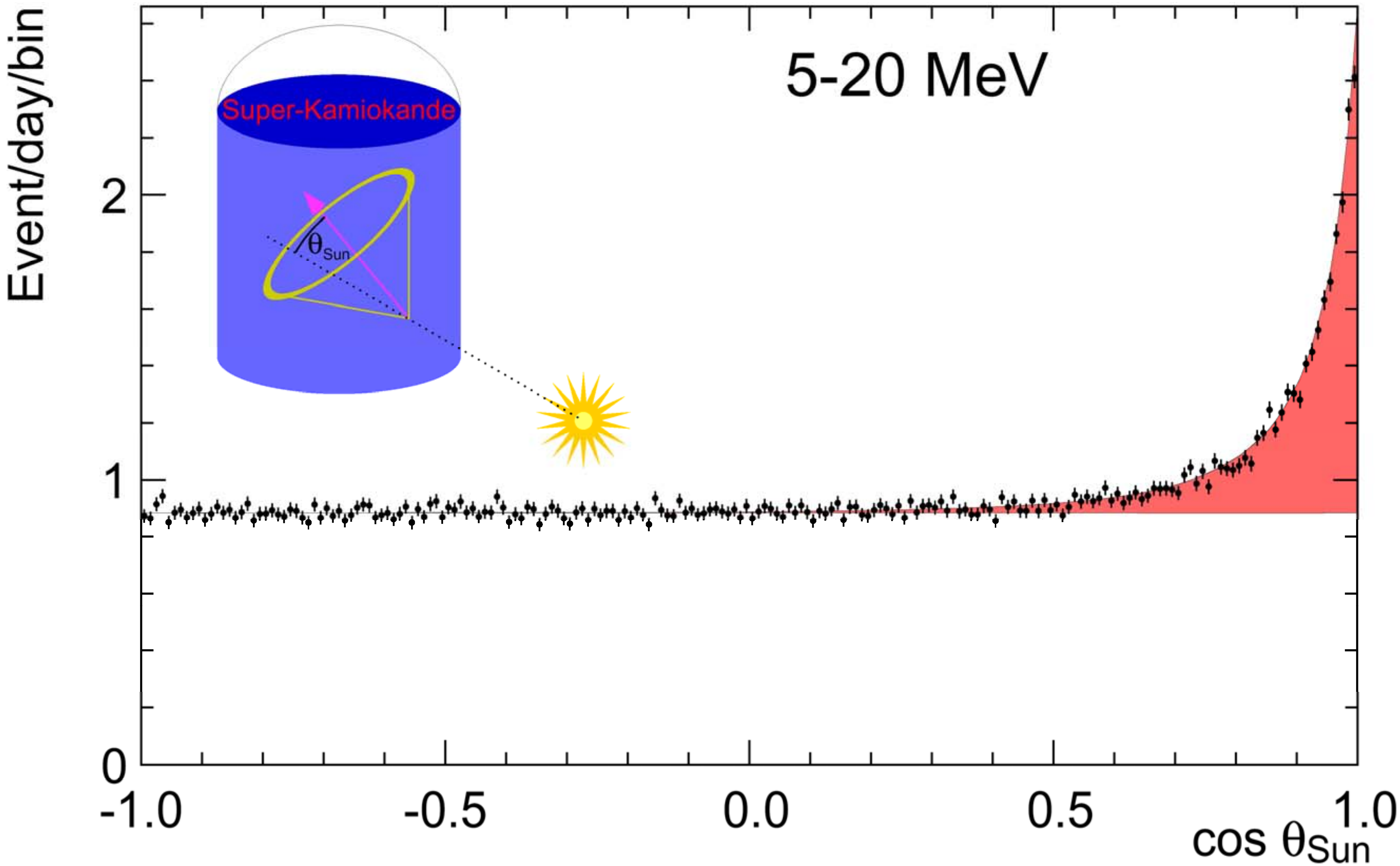


Solar orbit viewed with neutrinos.



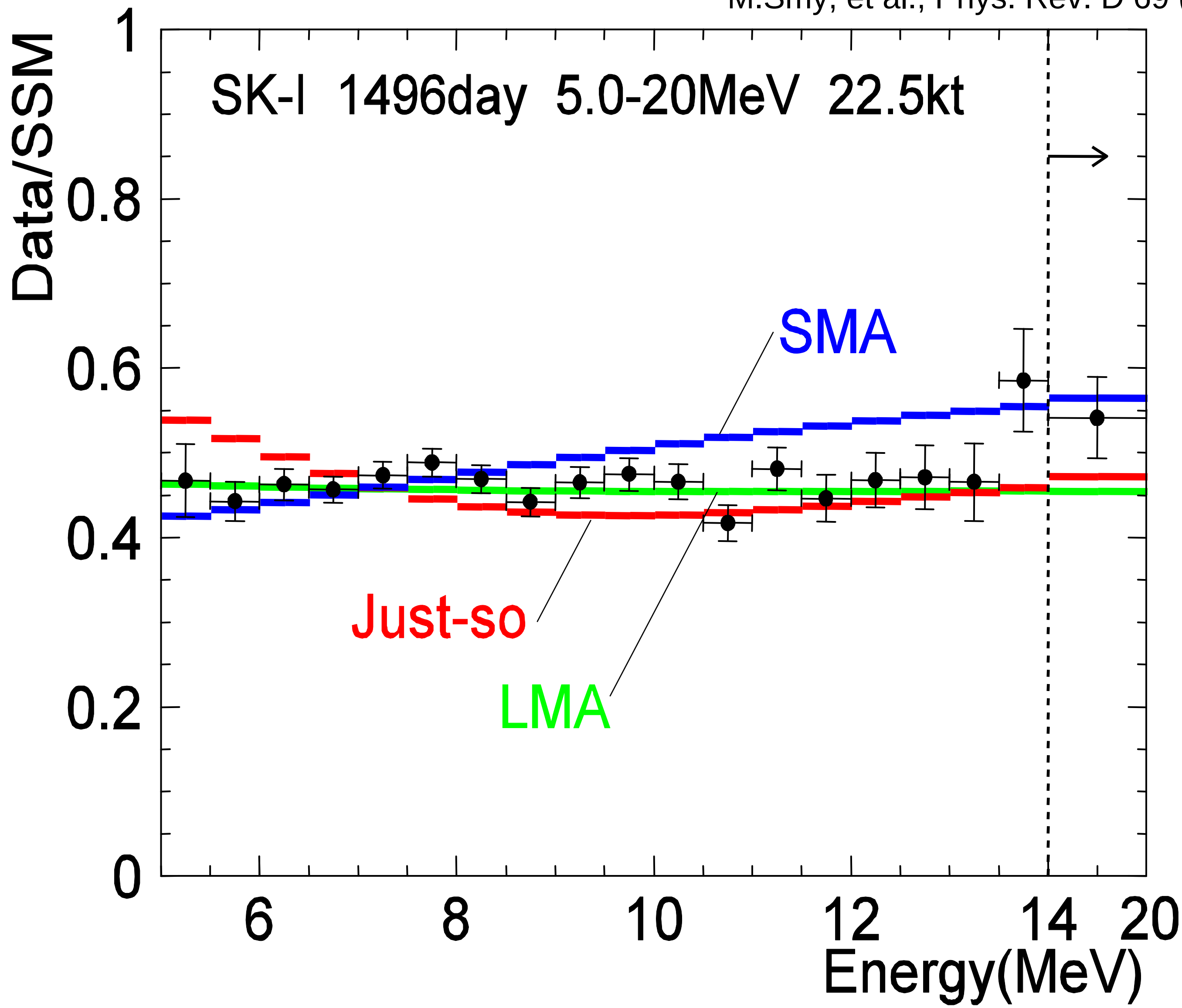
ν Signal From Solar Direction (5 MeV<)

S.Fukuda et al., Phys. Lett. B 539 (2002) 179.

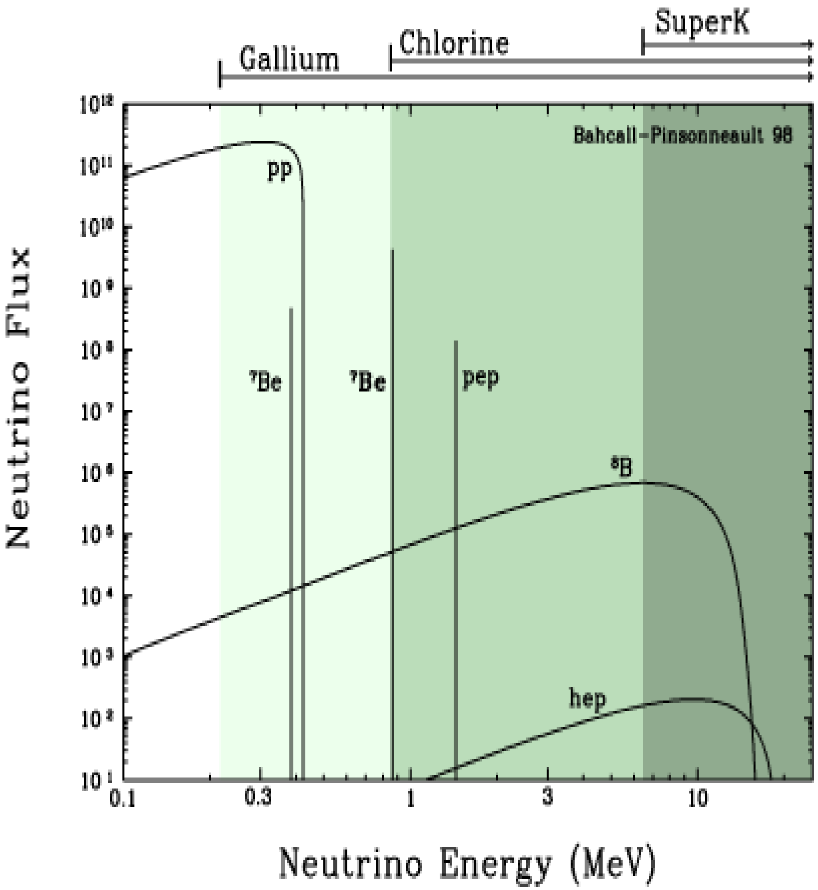


Comparison of Measured Electron Energy Spectrum and B^8 Decay Neutrinos

M.Smy, et al., Phys. Rev. D 69 (2004) 011104



Solar Neutrino Data



Rate measurements

	Target	Data / SSM (BP2000.2)
· Homestake	^{37}Cl	0.34±0.03
· SAGE	^{71}Ga	0.55±0.05
· GALLEX+GNO	^{71}Ga	0.55±0.05
· Super-K	e^- (water)	0.465±0.016
· SNO (CC)	d (D_2O)	0.348±0.020
· SNO (NC)	d (D_2O)	1.01±0.13

B.T.Cleveland et al., Astrophys. J 496 (1998) 505

J.N.Abdurashitov et al., Nucl. Phys. Proc. Suppl. (Neutrino 2002) 118 (2003) 39

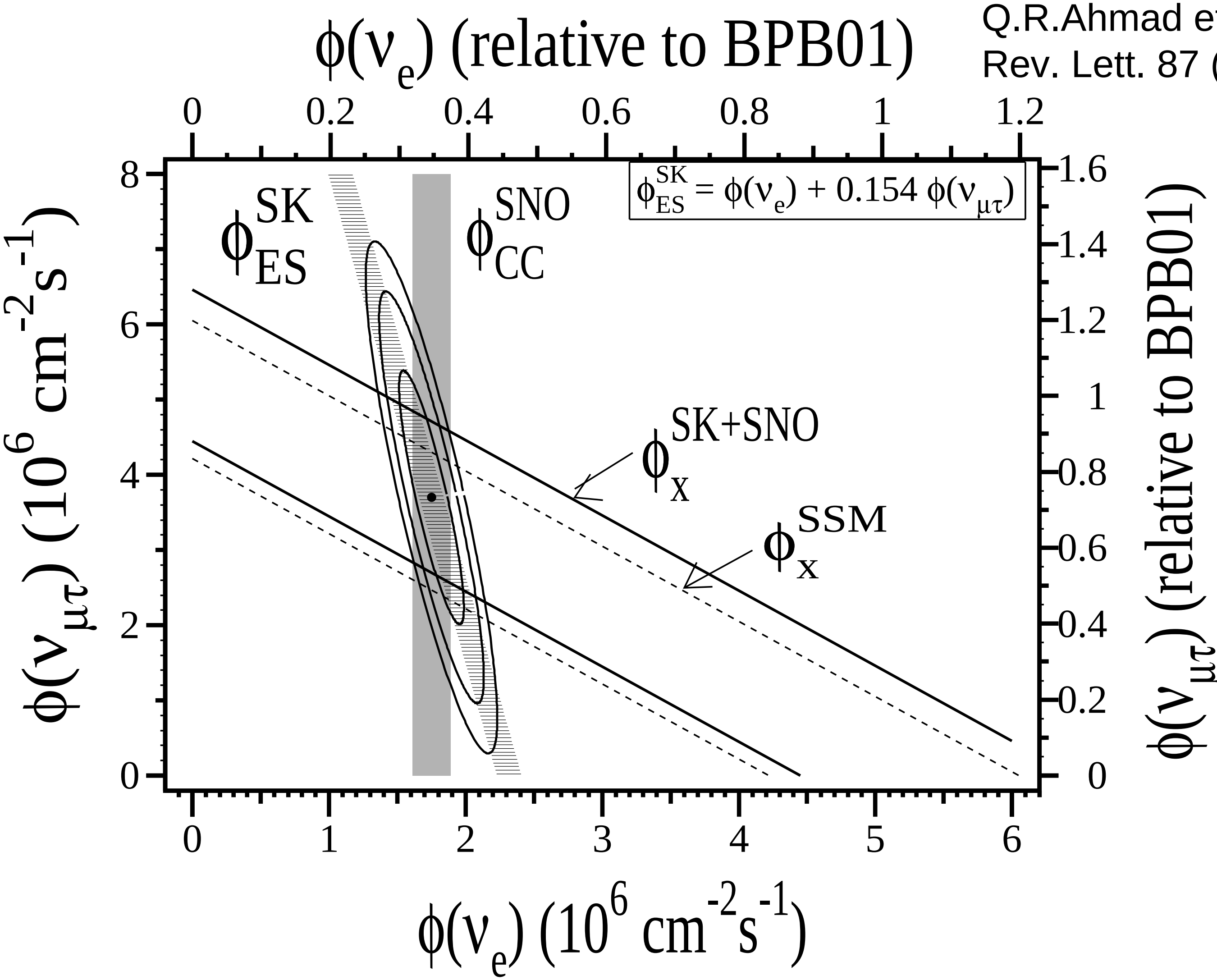
T.A.Kirsten for the GNO collab. Nucl. Phys. Proc. Suppl. (Neutrino 2002) 118 (2003) 33.

S.Fukuda et al., Phys. Lett. B 539 (2002) 179.

Q.R. Ahmad et al., Phys. Rev. Lett. 89 (2002) 011301

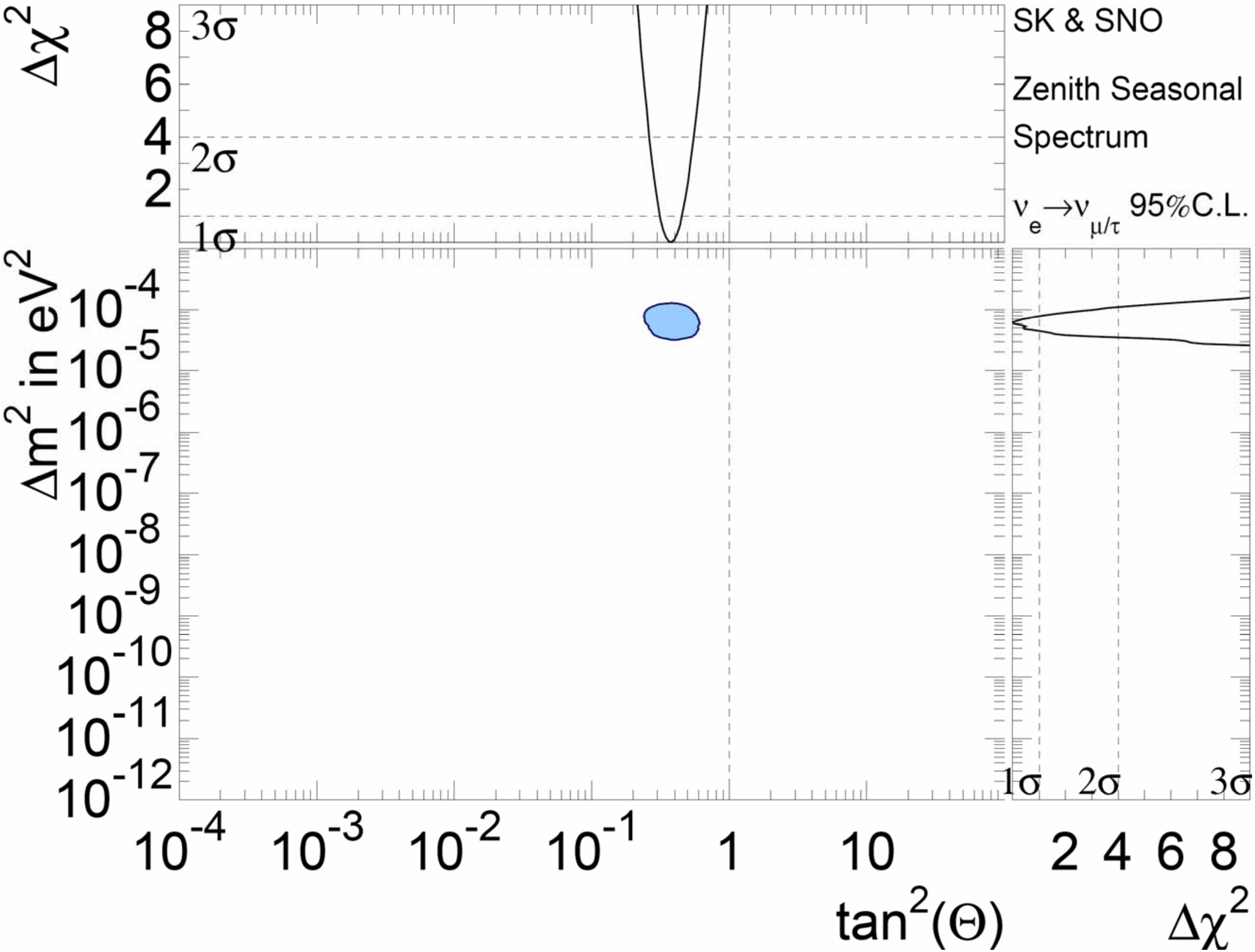
Deficit of Solar Neutrino Observed by Super-KamiokaNDE and SNO (2001)

Q.R.Ahmad et al., Phys. Rev. Lett. 87 (2001) 071301.



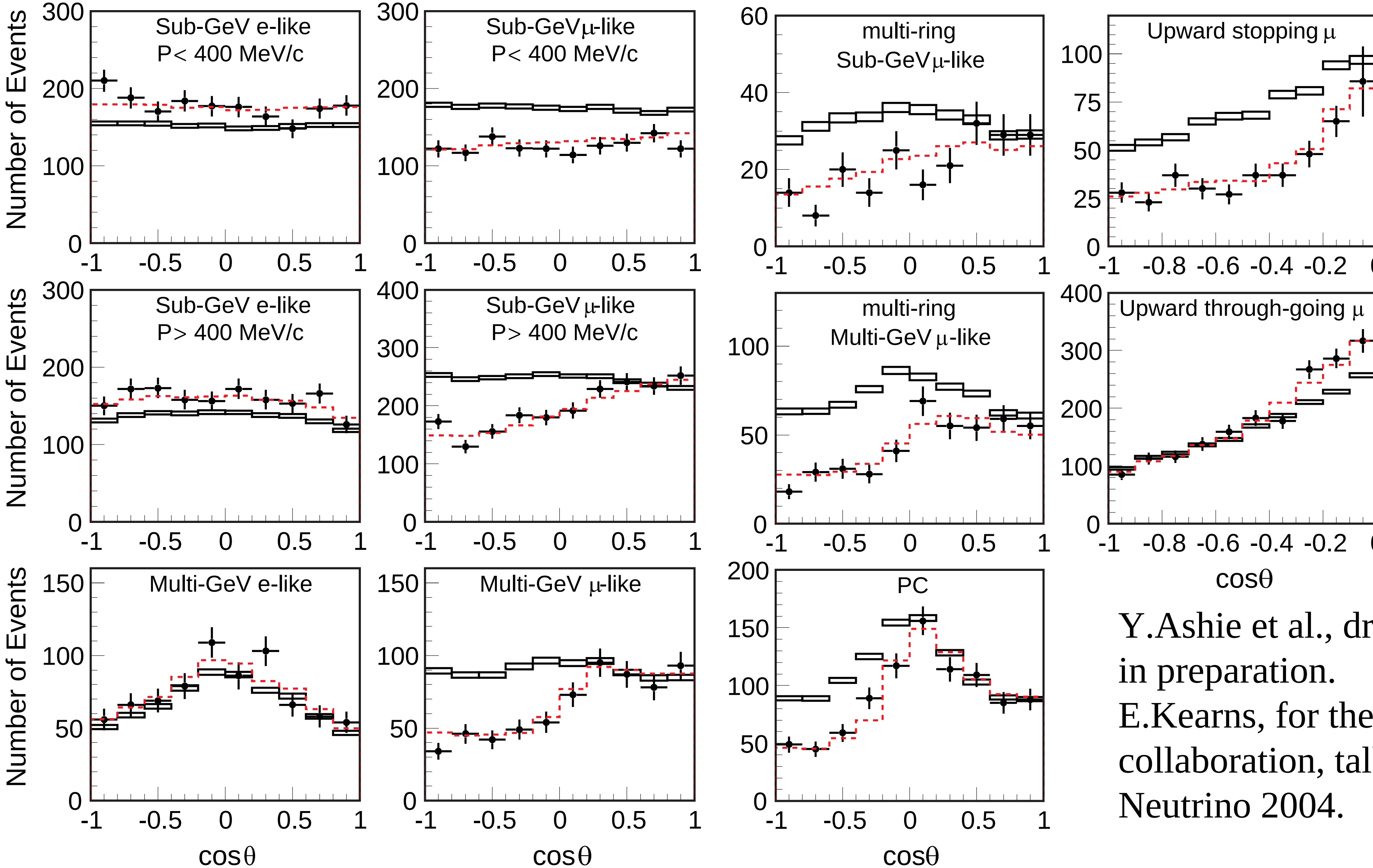
Solar Neutrino Oscillation Parameter

M.Smy, et al., Phys. Rev. D 69 (2004) 011104
Q.R. Ahmad et al., Phys. Rev. Lett. 89 (2002) 011301



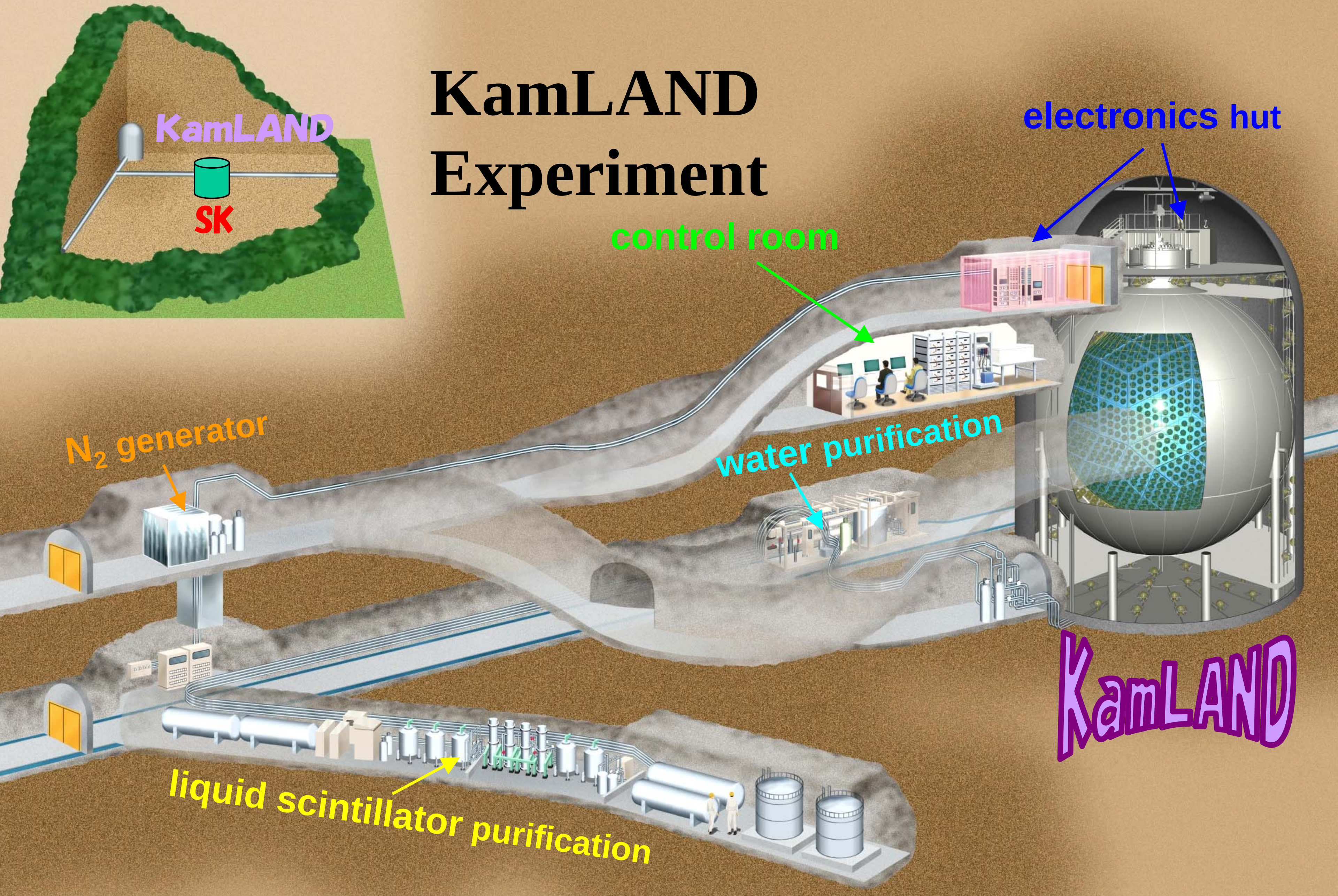
Zenith Angle Distribution of Neutrino Oscillation (SK)

1489day FC+PC data + 1646day upward going muon data



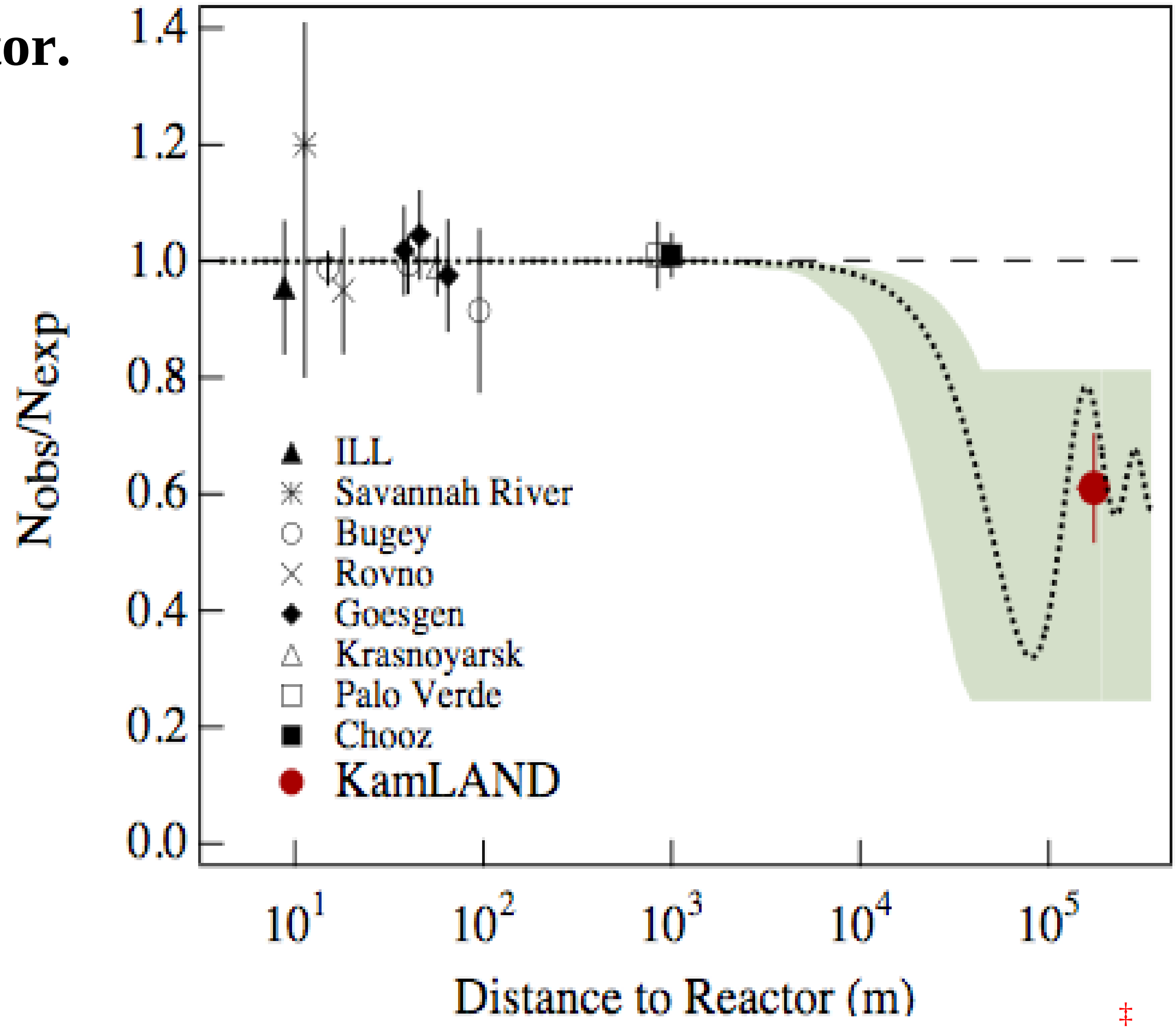
Y.Ashie et al., draft in preparation.
E.Kearns, for the SK collaboration, talk at Neutrino 2004.

KamLAND Experiment



Source: Research Center for Neutrino Science http://www.awa.tohoku.ac.jp/KamLAND/index_old.htr

KamLAND detected the anti electron-neutrinos from nuclear reactor.



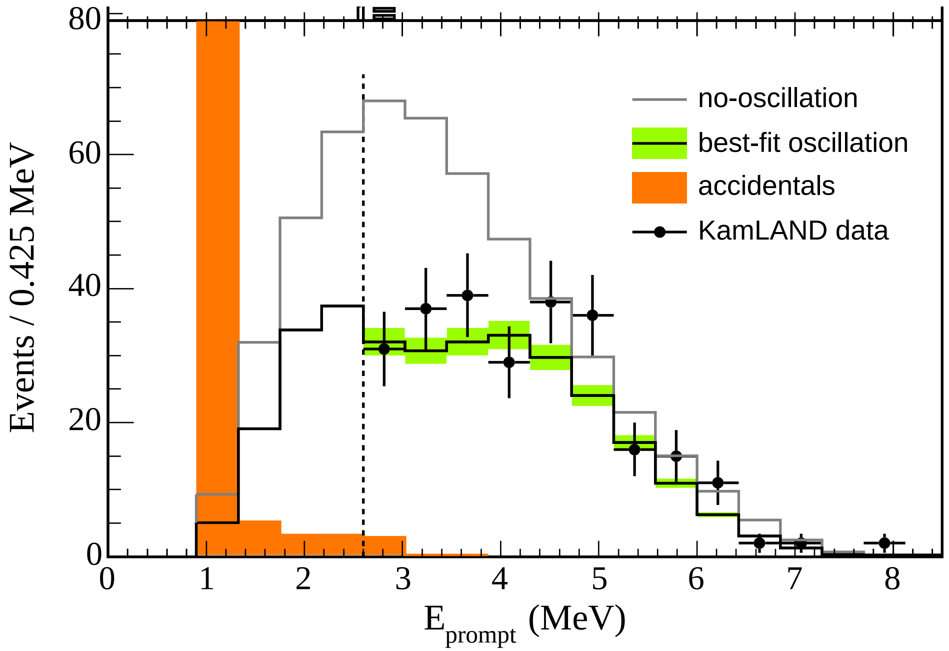
K.Eguchi et al., Phys. Rev. Lett. 90 (2003) 021802

Recent Results From KamLAND
(anti-ν_e behaves like ν_e)

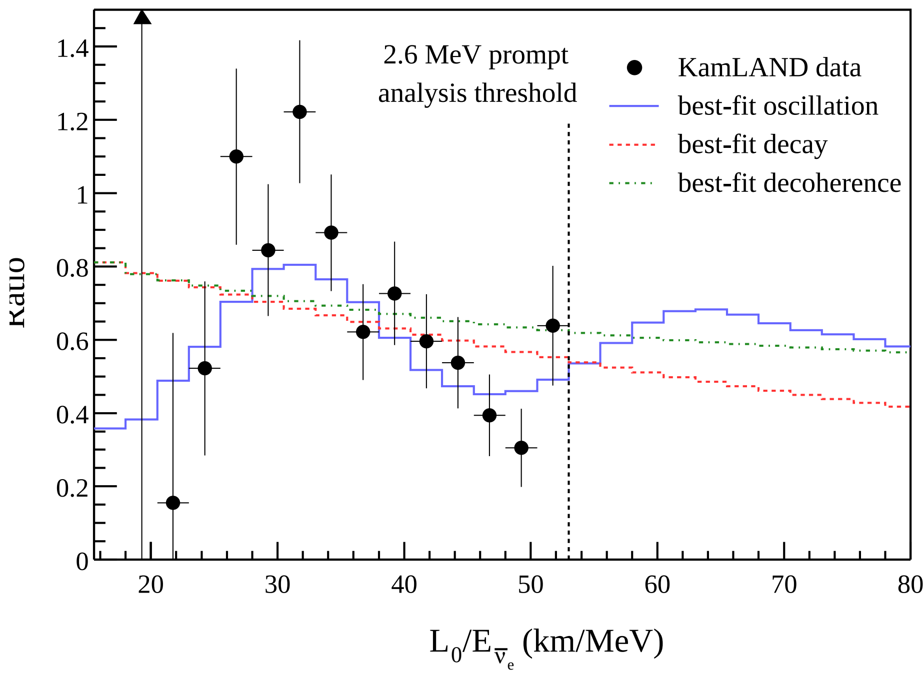
766 ton･year exposure

T.Araki et al., hep-ex/0406035

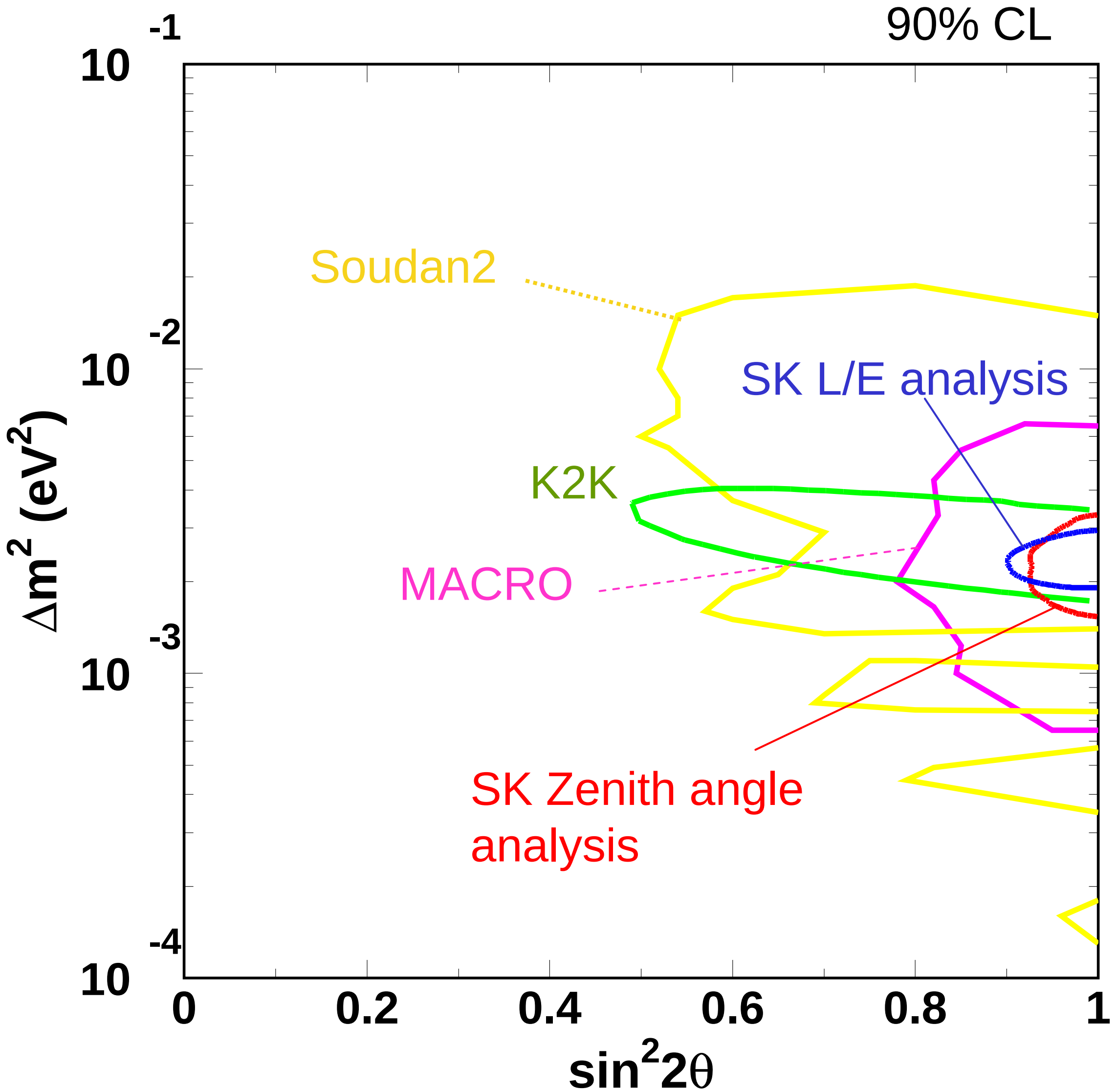
Energy spectrum



L/E distribution



ν_μ -ν_τ Oscillation Parameter Range



M.Sanchez et al., Phys. Rev. D 68 (2003) 113004

M.Ambrosio et al., Phys. Lett. B 566 (2003) 35.

T.Nakaya (for the K2K collaboration), presented at Neutrino2004.

Y.Ashie et al., hep-ex/0404034

Y.Ashie et al., draft in preparation; E.Keanrs, for the SK collaboration, talk at Neutrino2004.

In conclusion,

- **The oscillation parameters for all three types of neutrinos has been already determined, and in the future accelerator-based neutrino oscillation experiments, the values of as-yet unknown 1-3 mixing angles are also likely to be obtained.**

- **KamLAND detector may allow the anti-ν_e tomography of U and Th in the interior of the earth.**

- **It is fascinating at the same time very difficult to see the universe at three seconds after the Big Bang through observation of Cosmic Neutrino Background (CNB). By understanding the non-zero neutrino masses, we know that extremely low energy neutrinos behave total reflection in the superconductive metal, adding accurate directions to the measurements, however, the detection of extremely low energy neutrinos is still an arduous task.**

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- Heisei Foundation for Basic Science helps advance basic science in Japan. Seeking for a broad range and consistent support from many Japanese citizens regardless of the condition of changing economy. We promote **1 yen per citizen per year** scale of support, and look for the local governments to take role of supporting memberships.
- We also look to have academic institutions to participate in **10 yen per person per year** scale of support; i.e., University of Tokyo.
- We intend to contribute and spread the pleasure of learning basic science across Japan.
- We give wards to the outstanding teachers who contributed to the pleasure of learning basic science among students.
- Thank you for your support!
- Refer to: **http://www.hfbs.or.jp**

Thank you for your patience.

Masatoshi Koshiba