Jan. 16, 2020

Berkeley Week at Kavli IPMU

Neutrino studies in Kamioka

ICRR and Kavli IPMU, The Univ. of Tokyo

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Outline

- *Kamiokande*
- *Super-Kamiokande*
- *Neutrino oscillations*
- *Future neutrino experiment in Kamioka*
- *Summary*

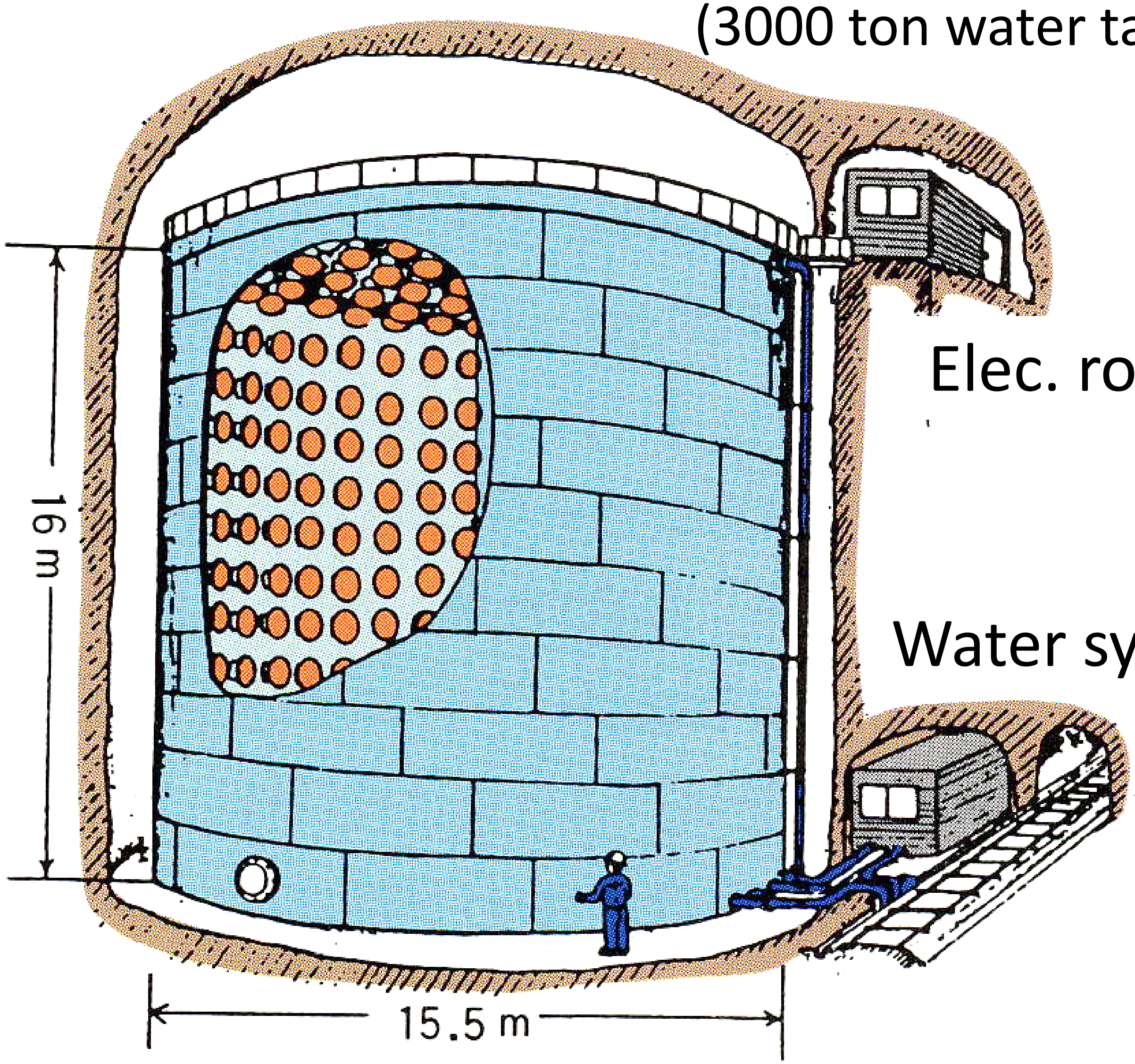
Kamiokande

Kamioka Nucleon Decay Experiment (Kamiokande)

- ✓ In the 1970's, newly proposed Grand Unified Theories predicted that protons should decay with the lifetime of about 10^{30} years.
- ✓ Several proton decay experiments began in the early 1980's. One of them was Kamiokande.

Kamiokande

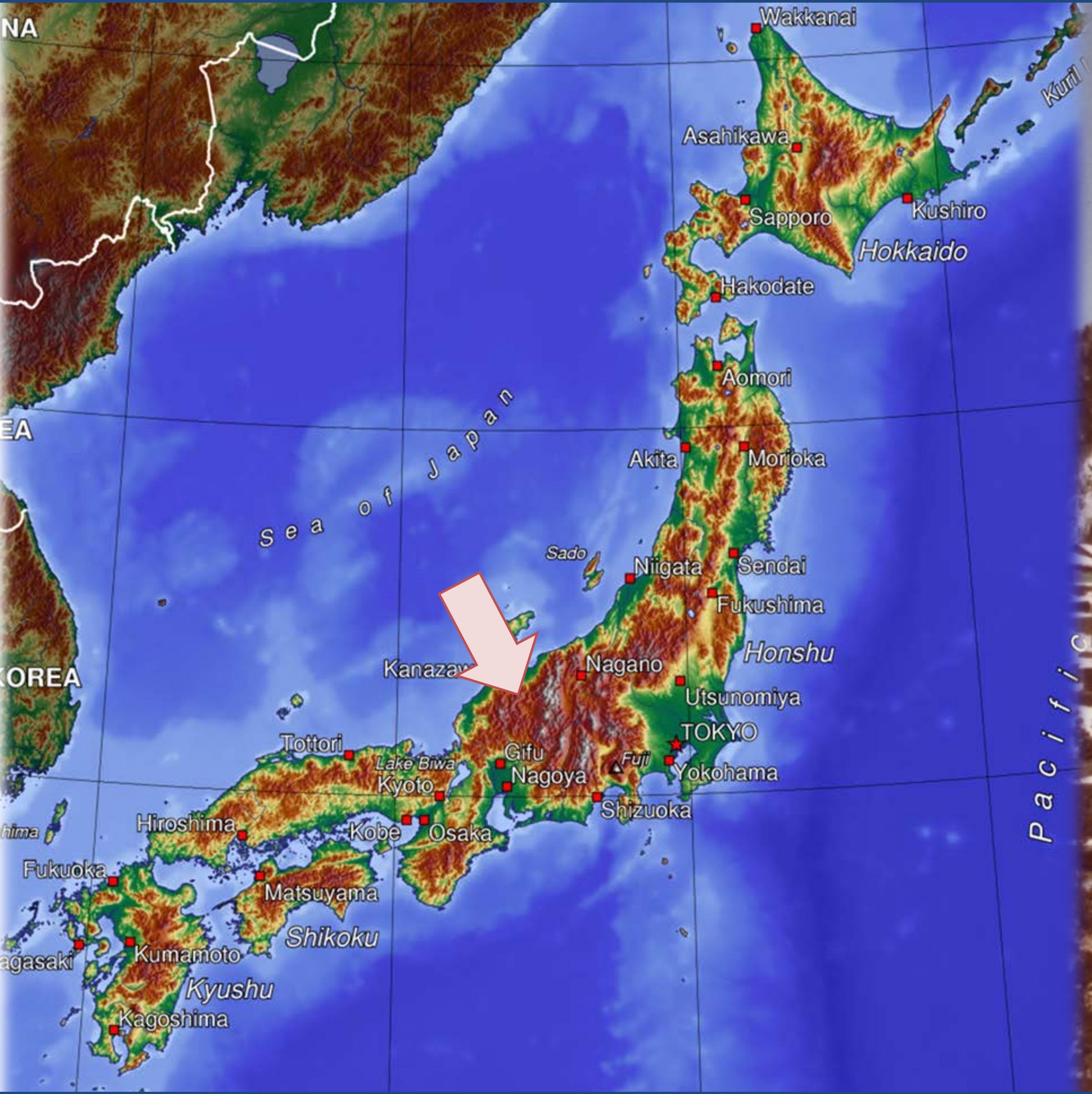
(3000 ton water tank)



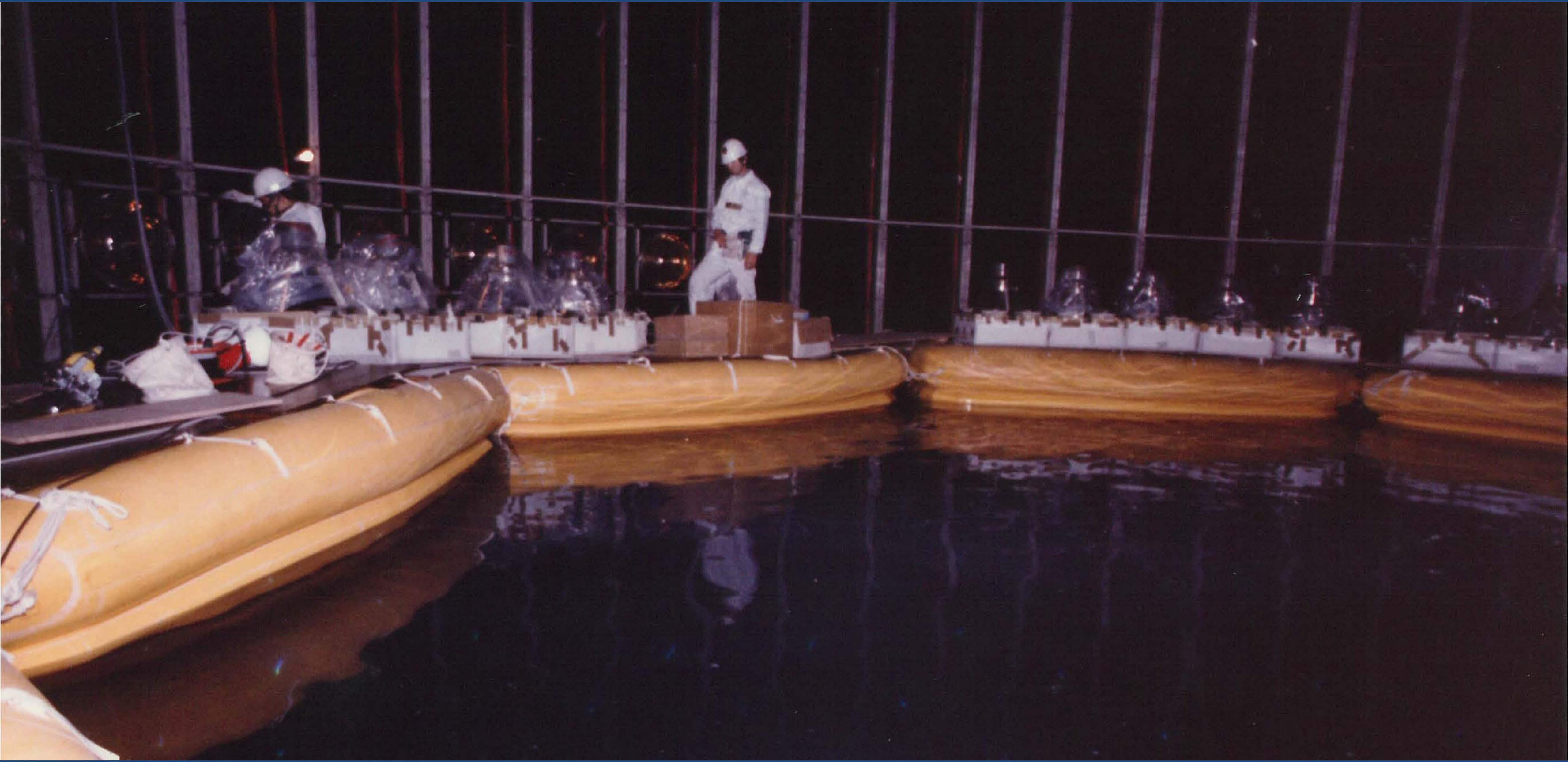
Elec. room

Water system

Where is Kamiokande?

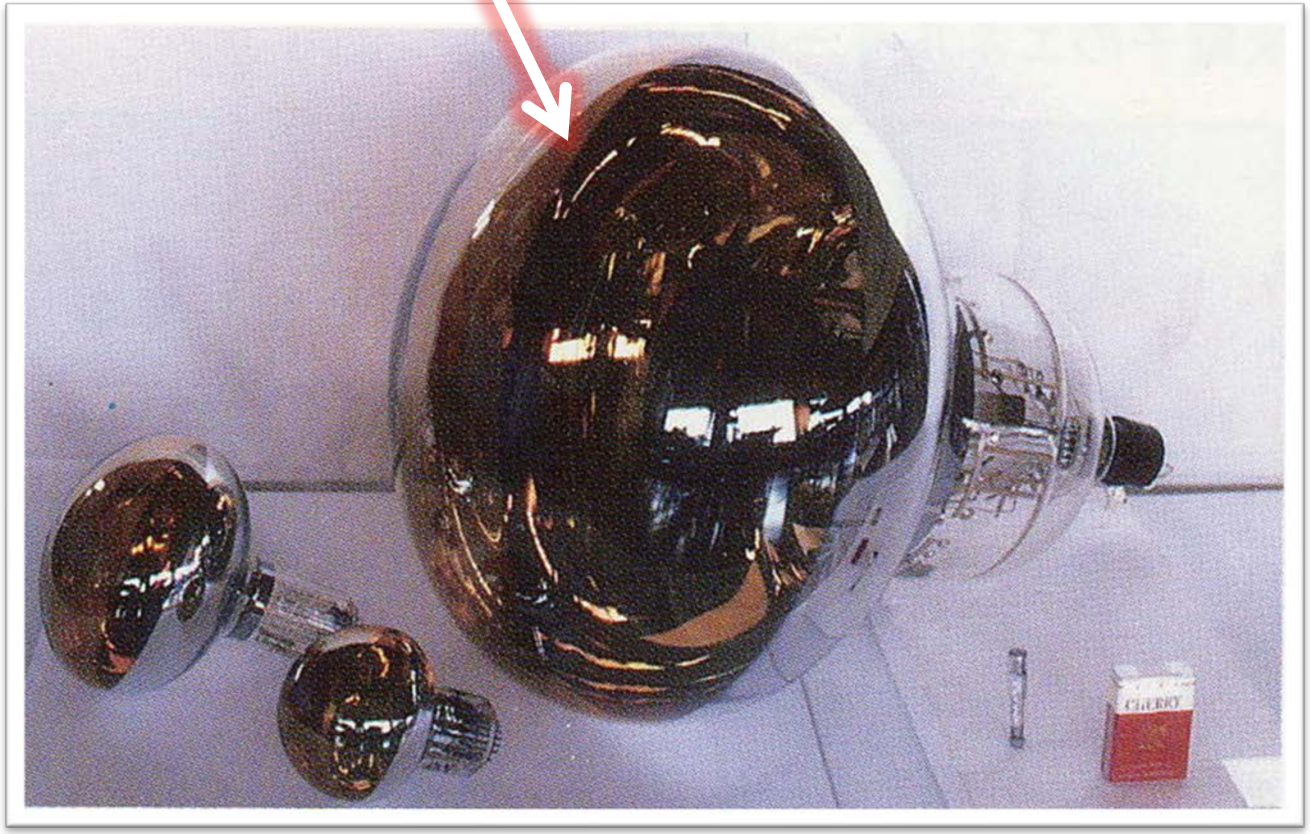


Construction of the Kamiokande detector (spring 1983)



Didn't observe proton decays, but…

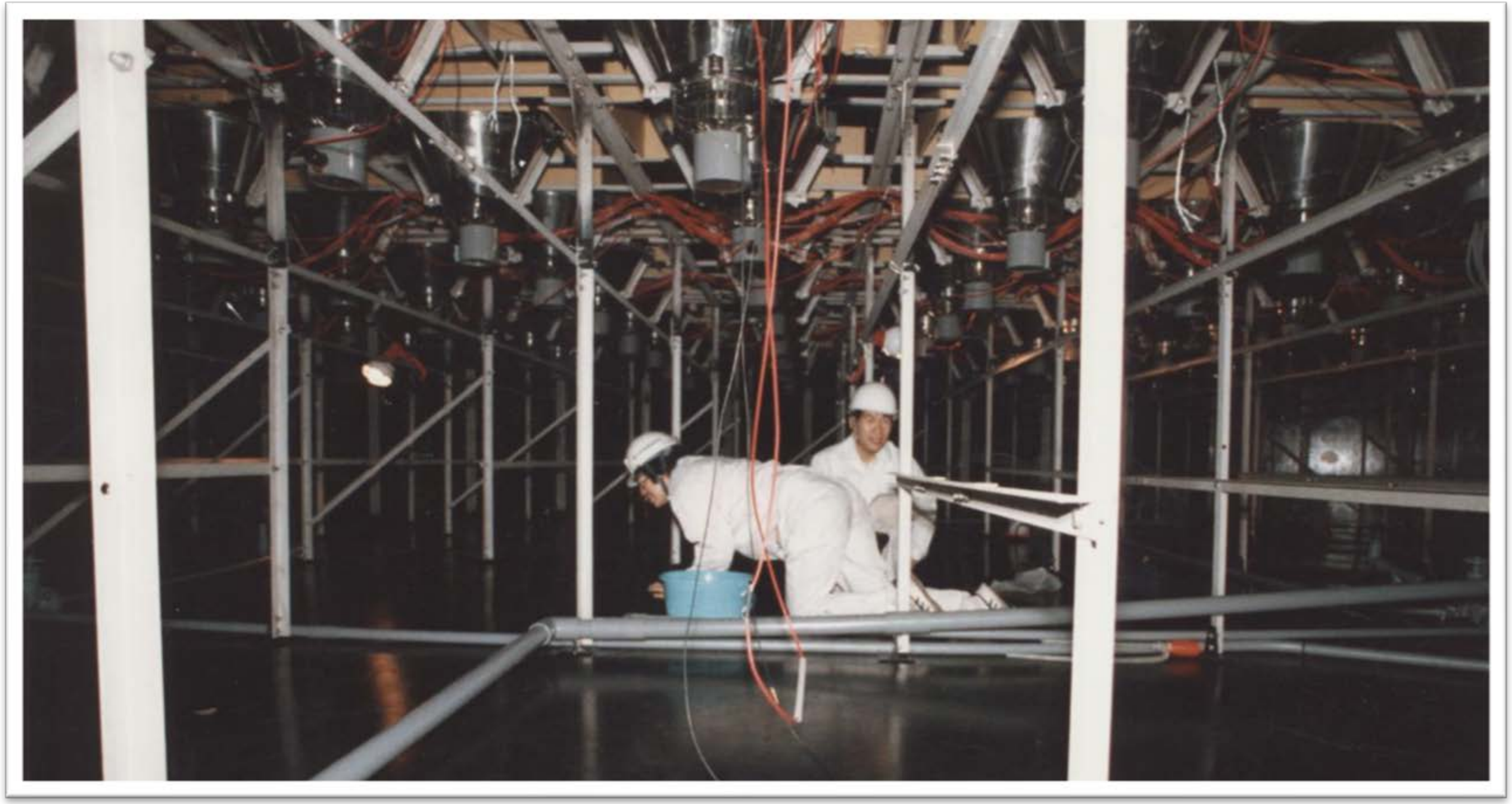
Photomultiplier tube used in Kamiokande



^{8}B solar neutrinos (whose energies are about 10 MeV) could be observed. (Many people thought that the missing solar neutrino problem must be due to some problems in either the solar model or in the experiment.)

Improvement of the Kamiokande detector to observe solar neutrinos. (Proposed by M. Koshiba)

Toward Kamiokande-II (1984-5)

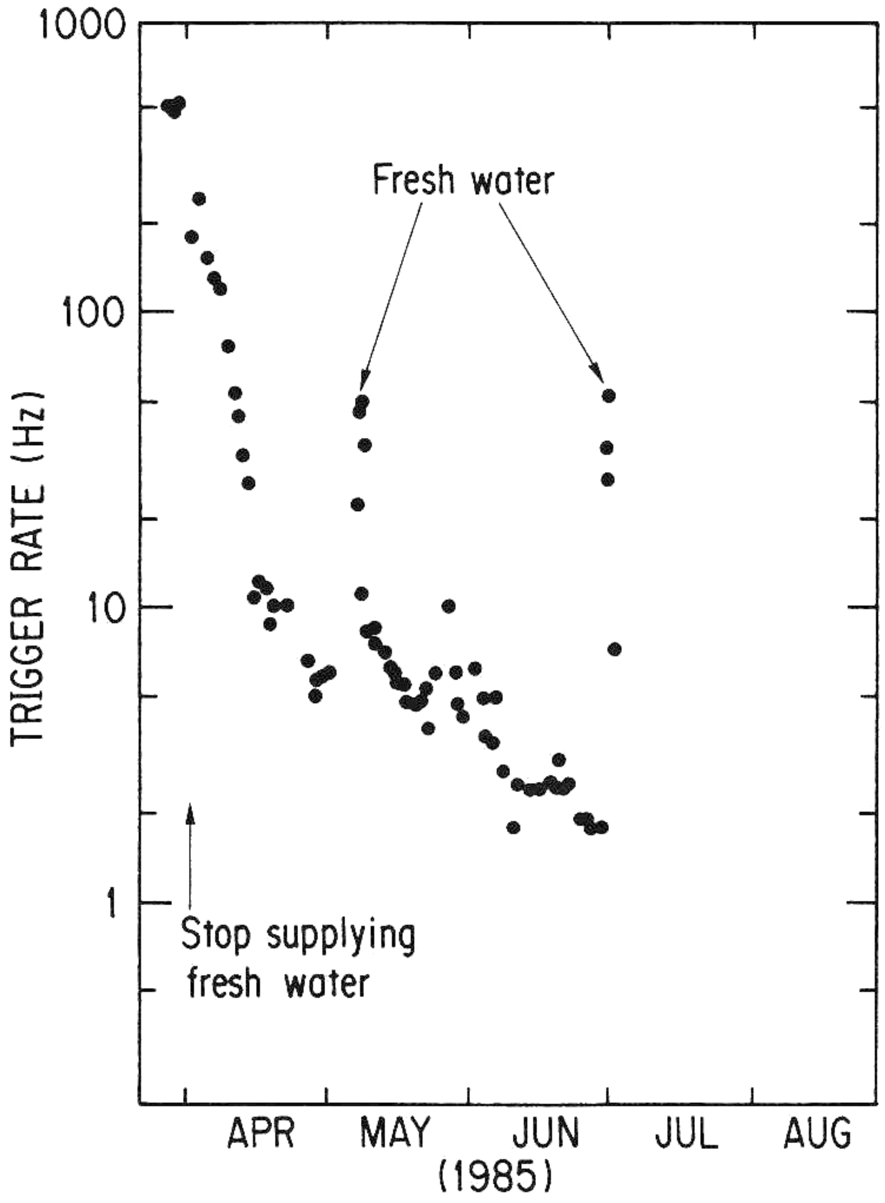


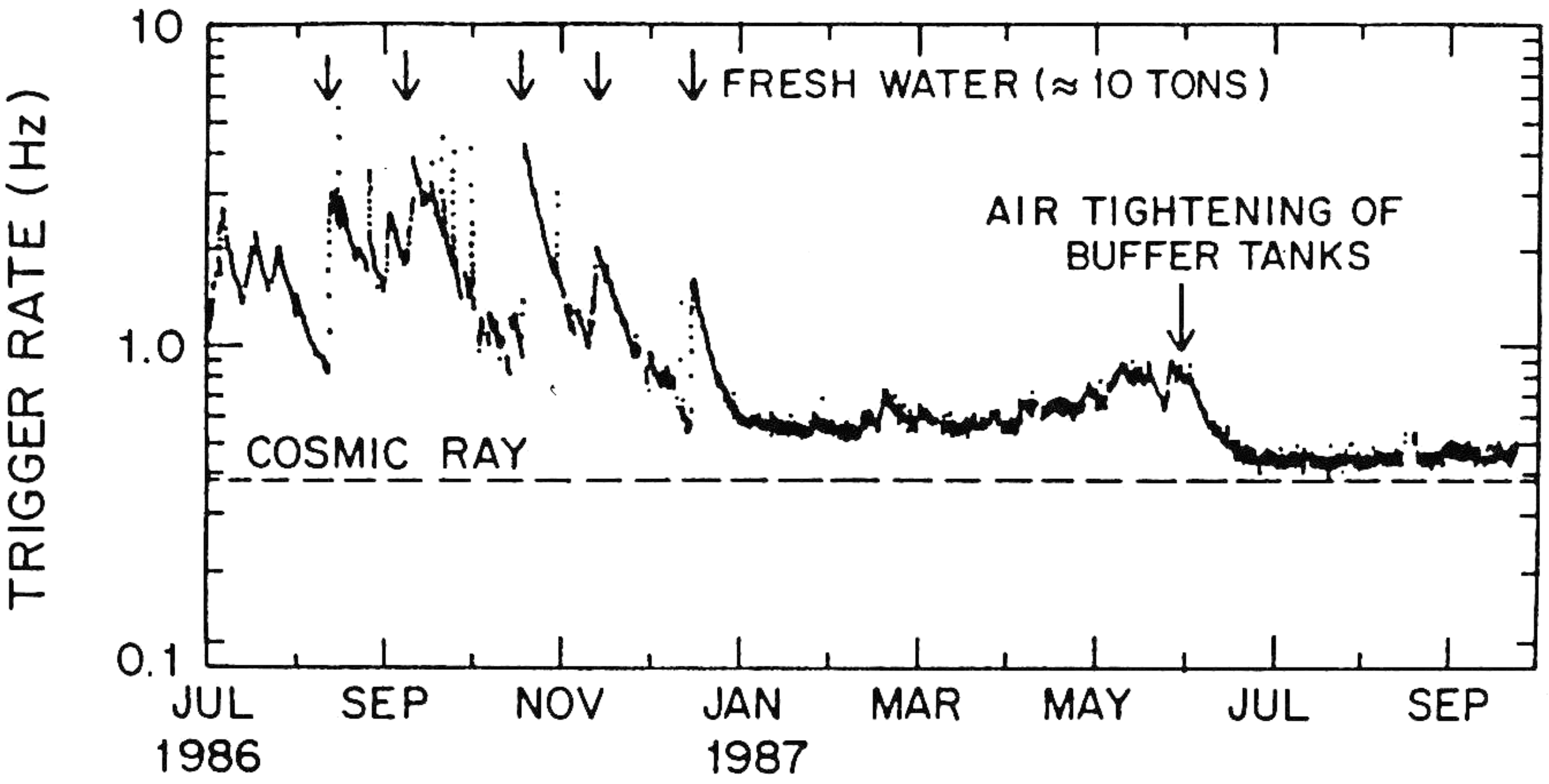
Construction of the bottom outer detector

Construction of the side outer detector (between the steel tank and the rock)

Detector improvement works during 1984 to 1986.

Radon...



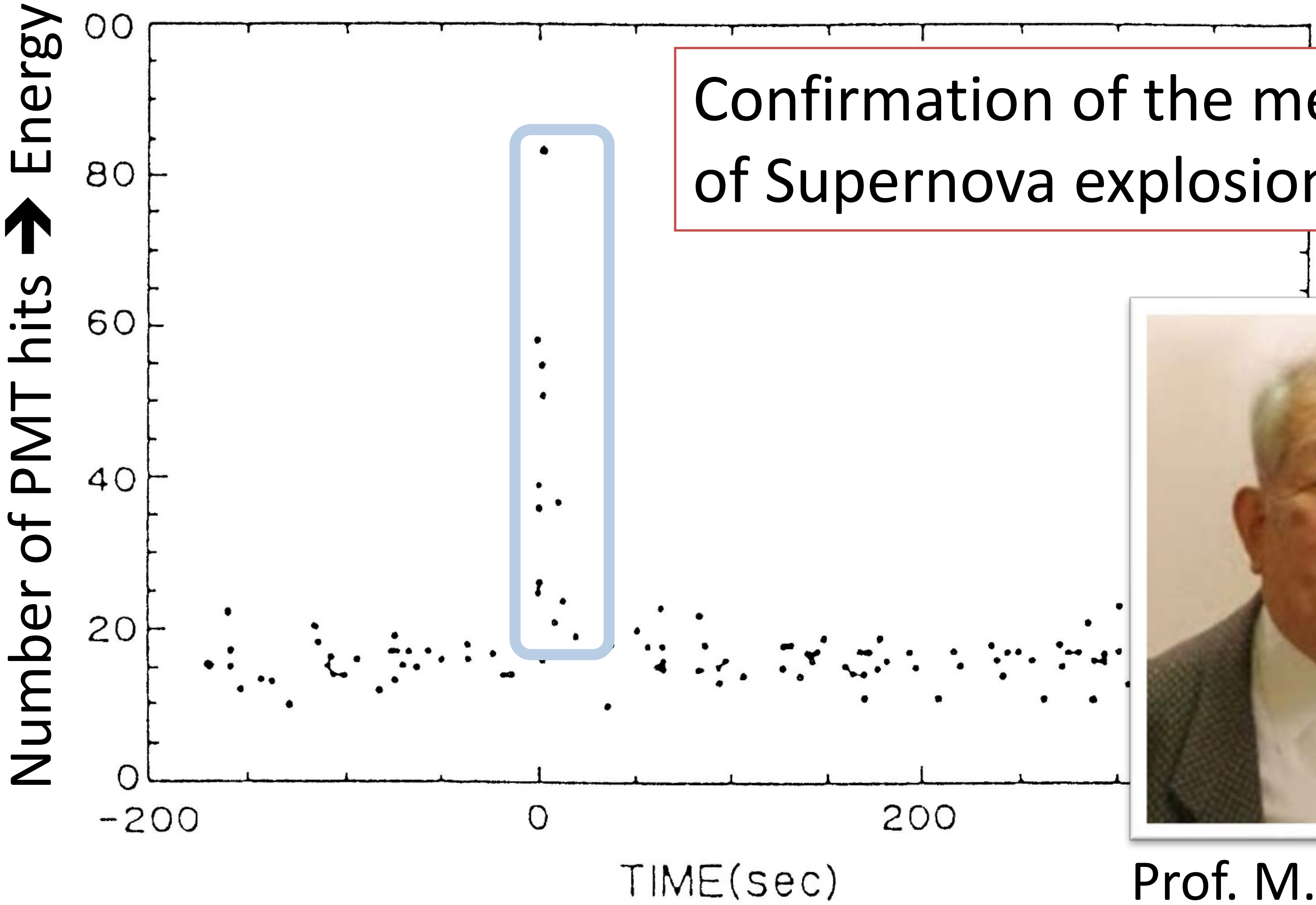


We did not know that Radon exists...

SN1987A (Feb. 23, 1987)

SN1987A (at LMC)

K. Hirata et al., Phys. Rev. Lett. 58 (1987) 1490.

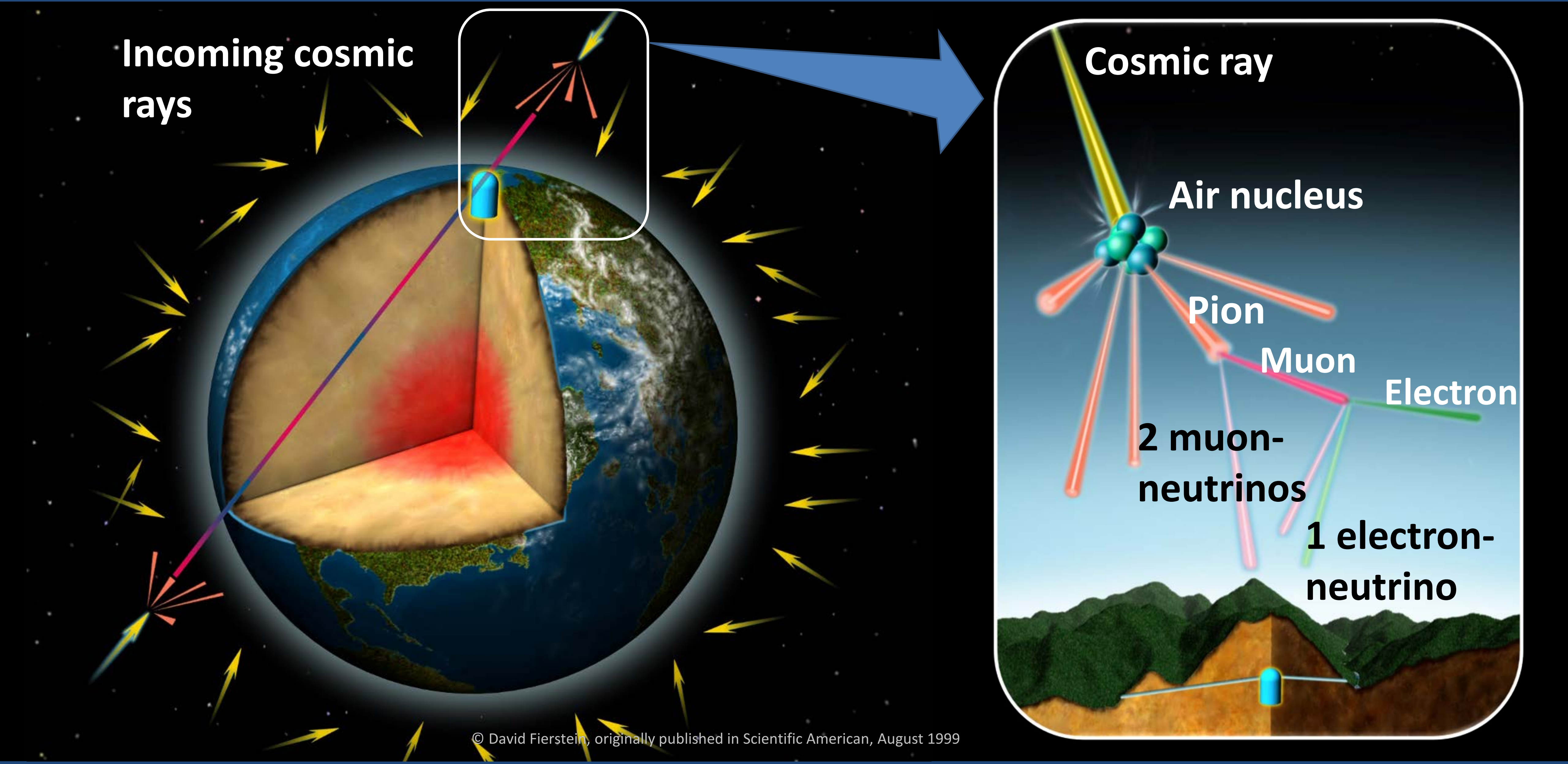


Confirmation of the mechanism of Supernova explosion!

Prof. M. Koshiba
Nobel prize in Physics (2002)

(The IMB and the Baksan experiments also observed the neutrino signal.)

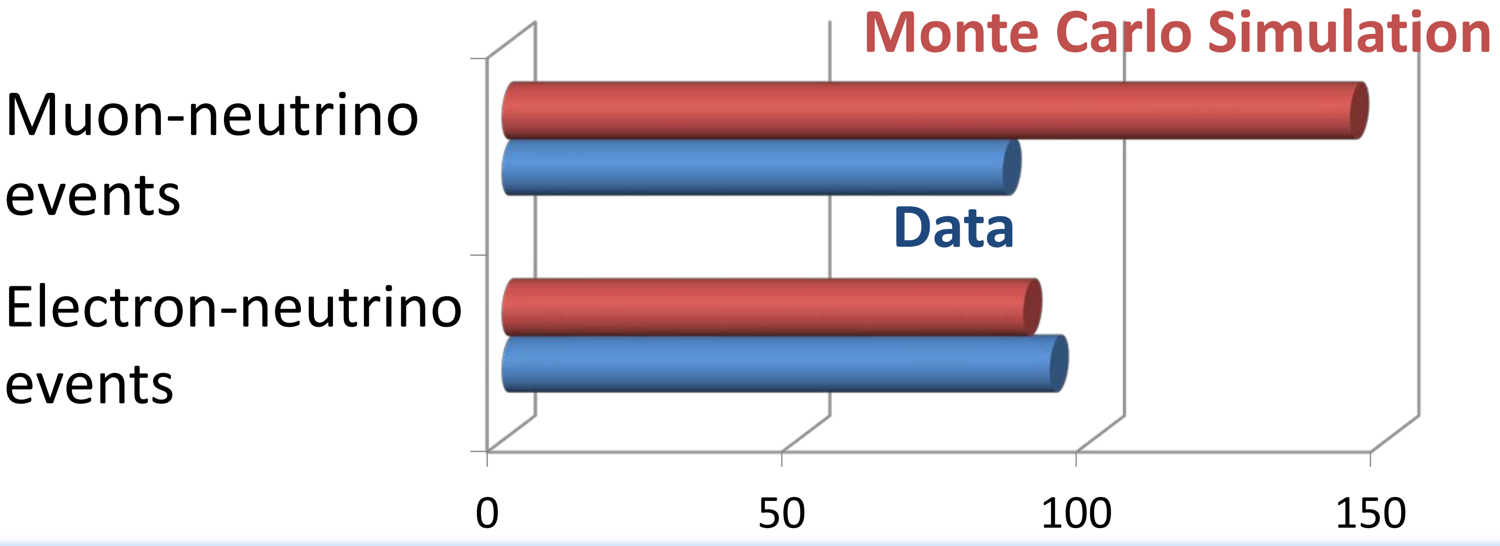
Atmospheric neutrinos



Atmospheric ν_μ deficit (1988)

- ✓ 1986, we wanted to improve the proton decay analysis. Therefore, several new software were developed. One of which was the particle identification (PID).
- ✓ As a test of new PID, the particle type for 1-ring atmospheric neutrino events was studied and realized the deficit of muon-neutrinos.

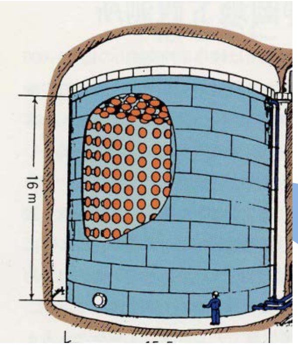
K. Hirata et al, Phys.Lett.B 205 (1988) 416.



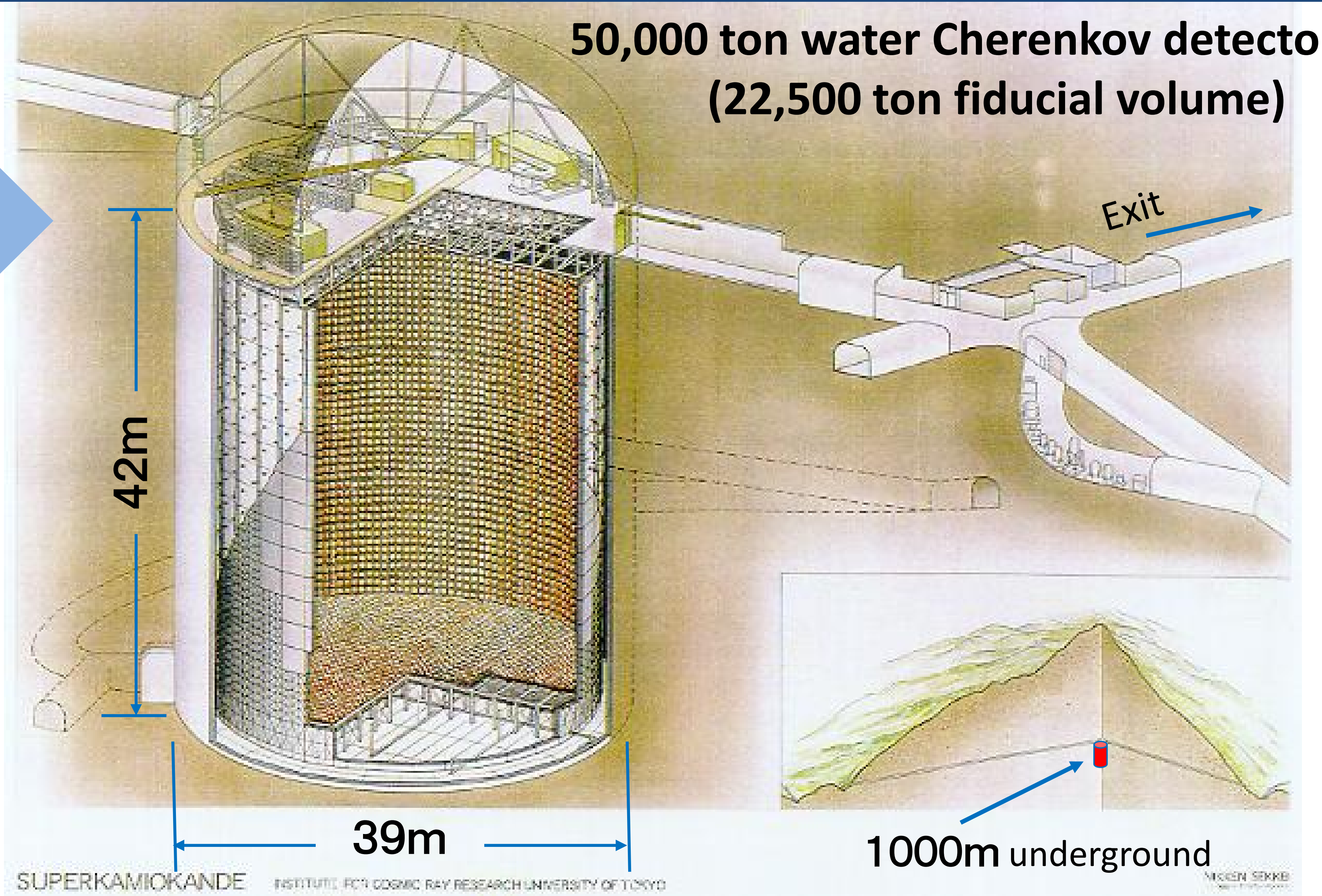
Of course, many people (both experimentalists and theorists) thought that there must be something wrong in the analysis… (Mixing angle cannot be large.)

Present: Super-Kamiokande

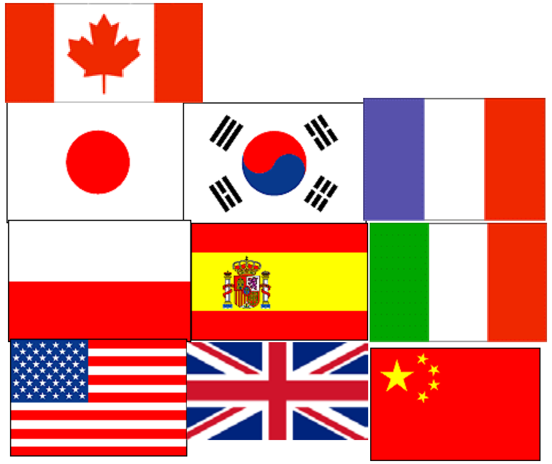
Super-Kamiokande detector



~20 times
larger mass



~180 collaborators

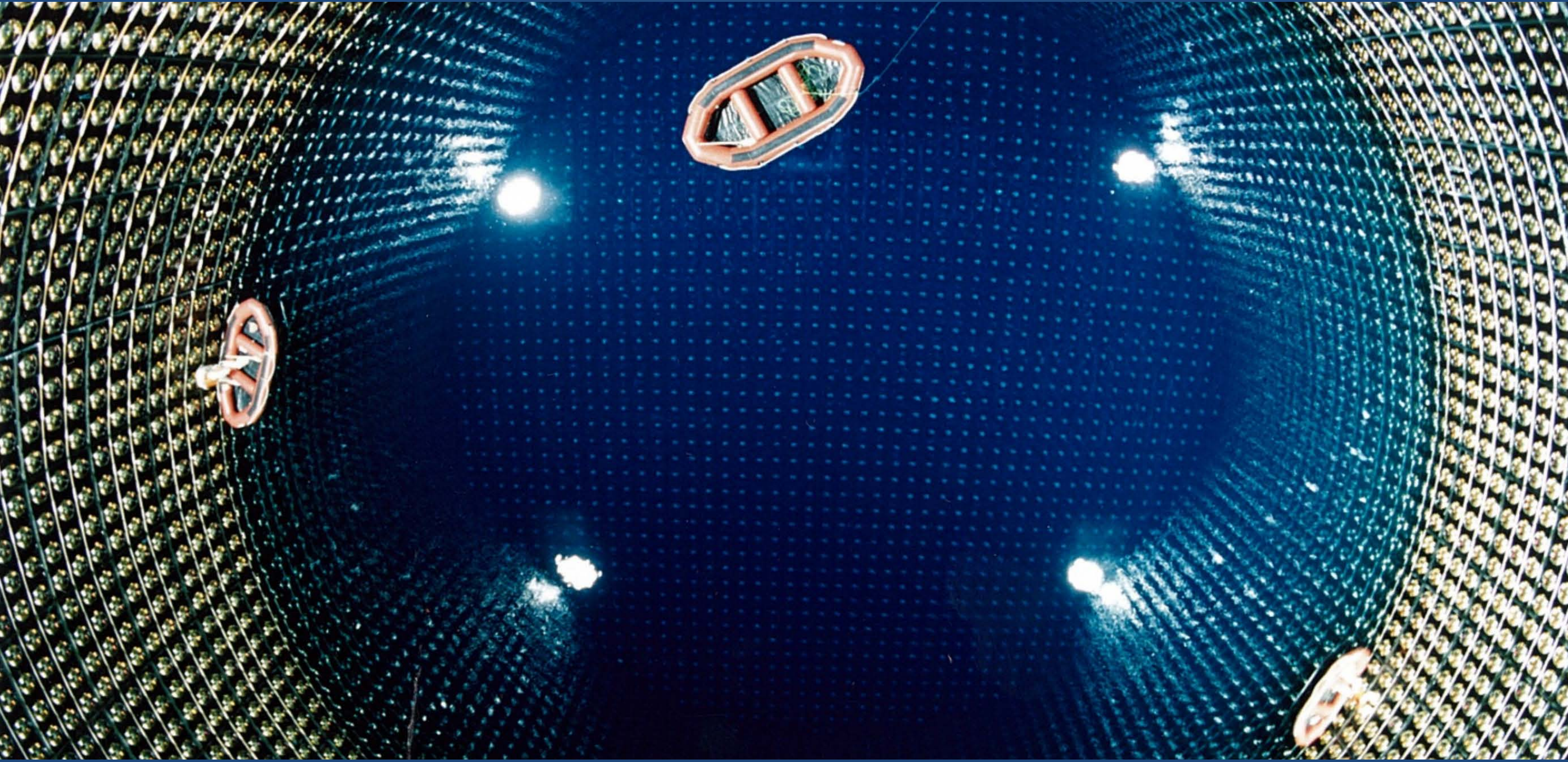


Super-Kamiokande construction (Summer 1995)

Kamiokande

Filling water in Super-Kamiokande

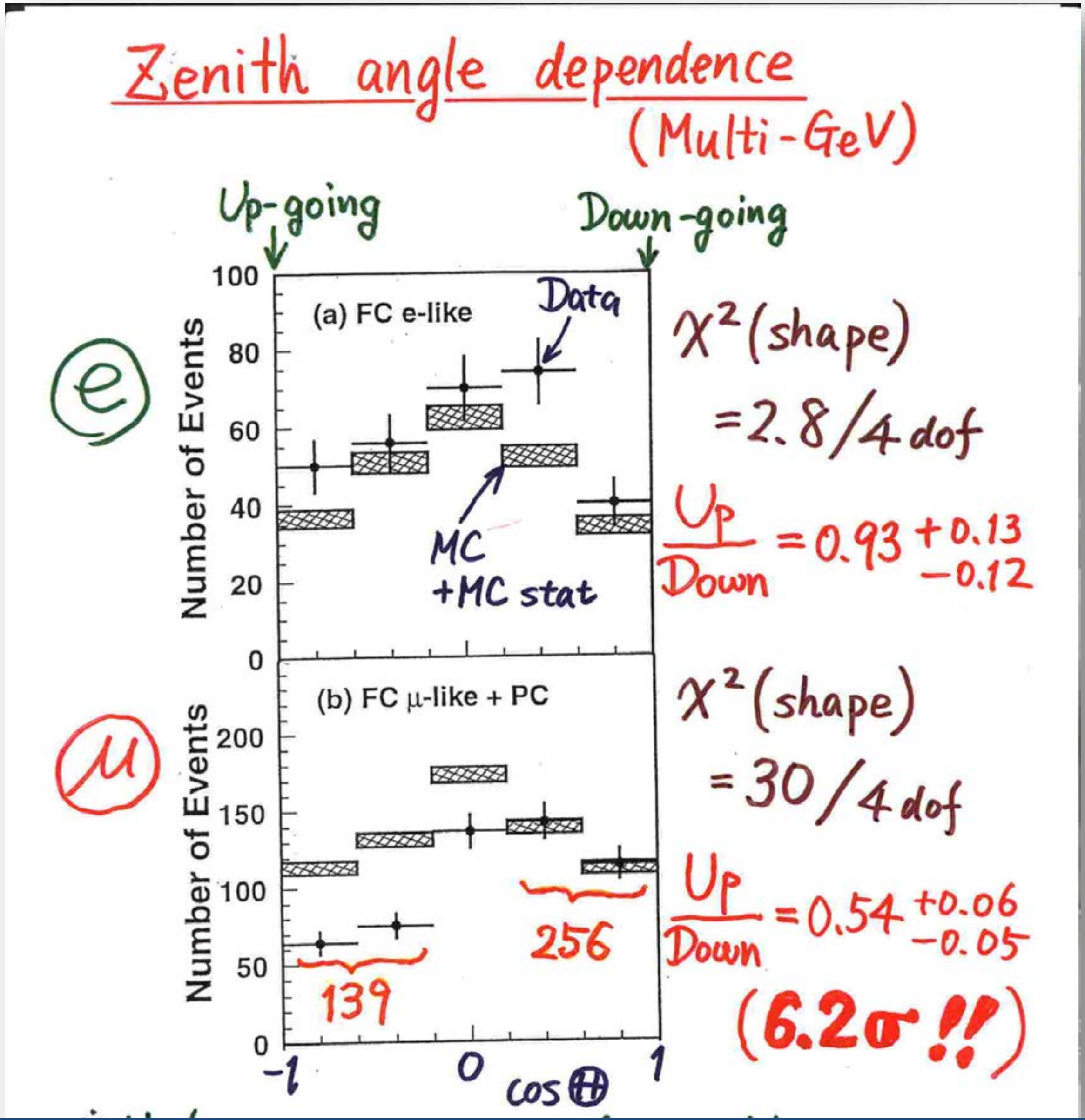
Jan. 1996

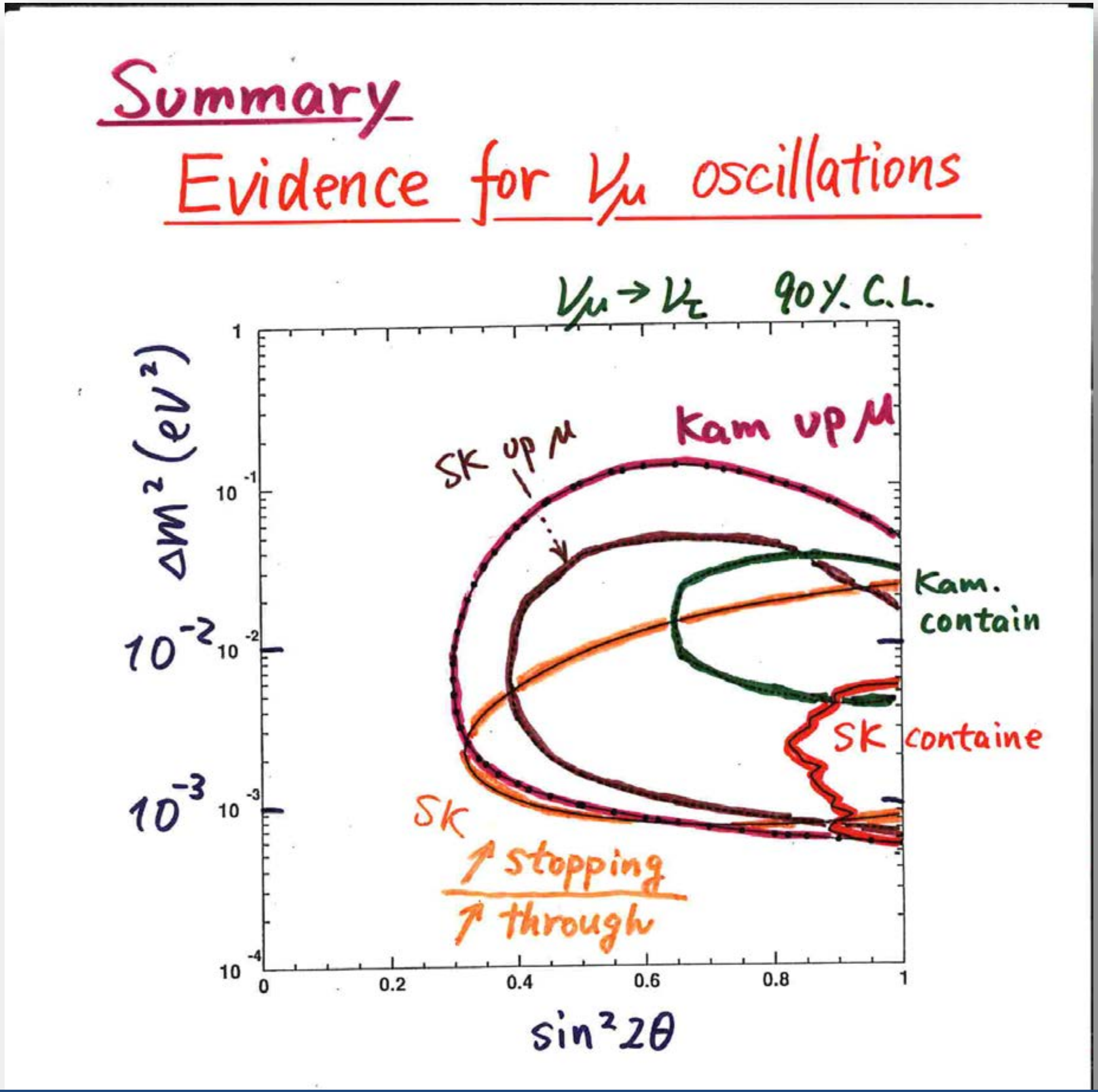


Neutrino oscillations

Evidence for neutrino oscillations (Super-Kamiokande @Neutrino '98)

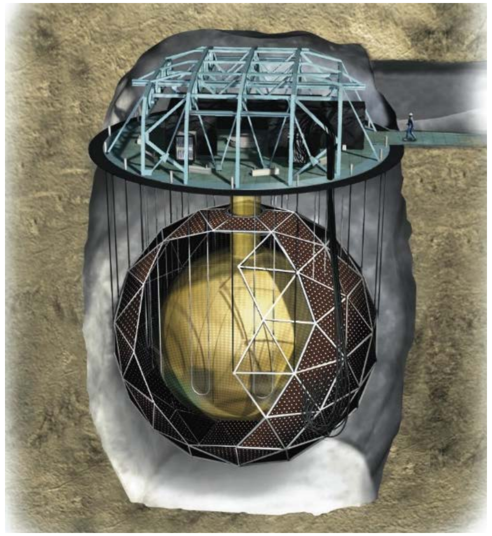
Y. Fukuda et al., PRL 81 (1998) 1562

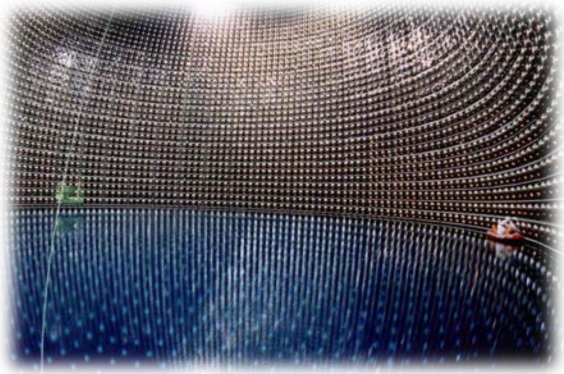


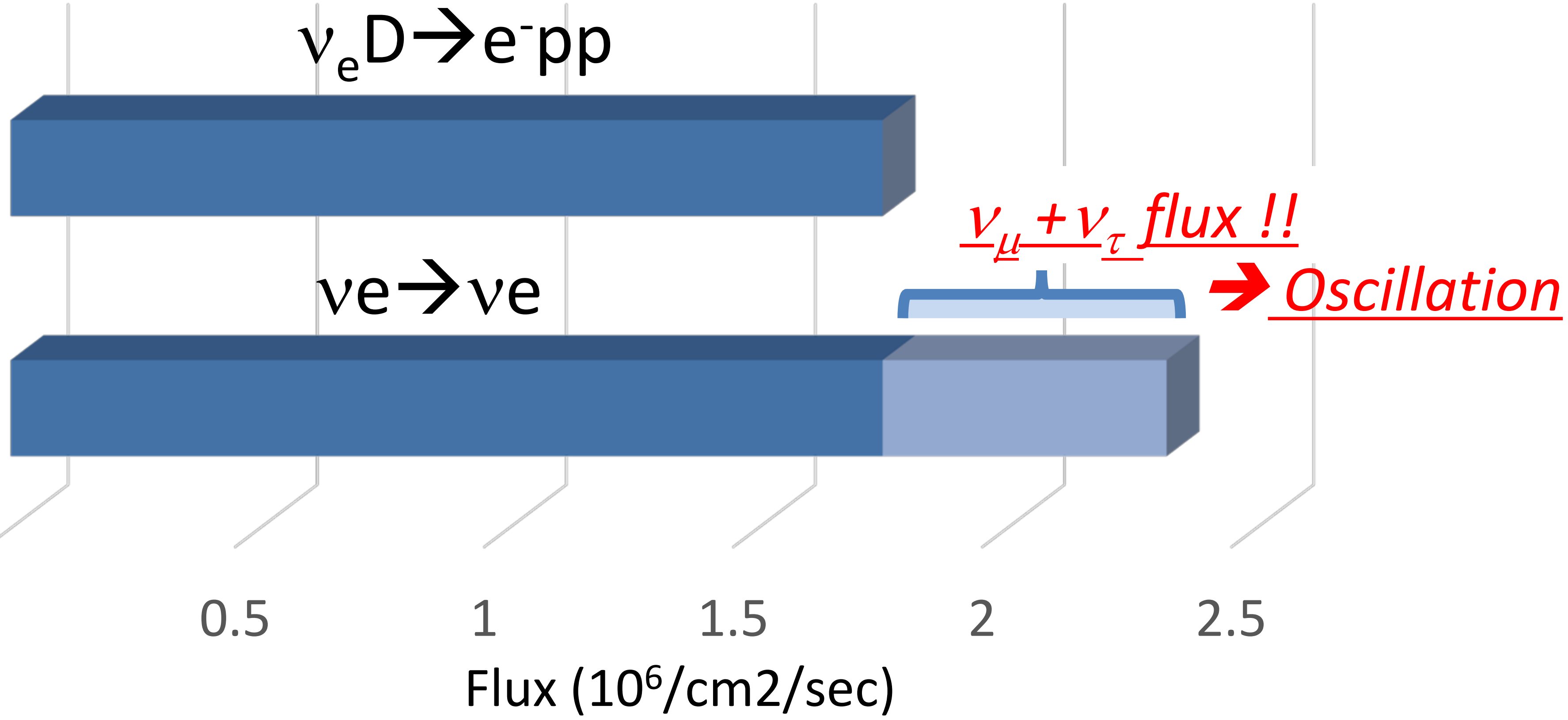


Collaboration with SNO in solar neutrino oscillations

SK, PRL 86 (2001) 5651
SNO PRL 87 82001) 071301
SNO PRL 89 (2002) 011301
SNO PRC 72, 055502 (2005)







(Later, SNO had more direct evidence for oscillations with NC measurement. Also KamLAND played a very important role.)

Other contribution of Super-Kamiokande to neutrino physics

Accelerator based long baseline neutrino oscillation experiments

K2K experiment (1999 – 2004)

Confirmation of neutrino oscillation with accelerator beam.

T2K experiment (2010 -)

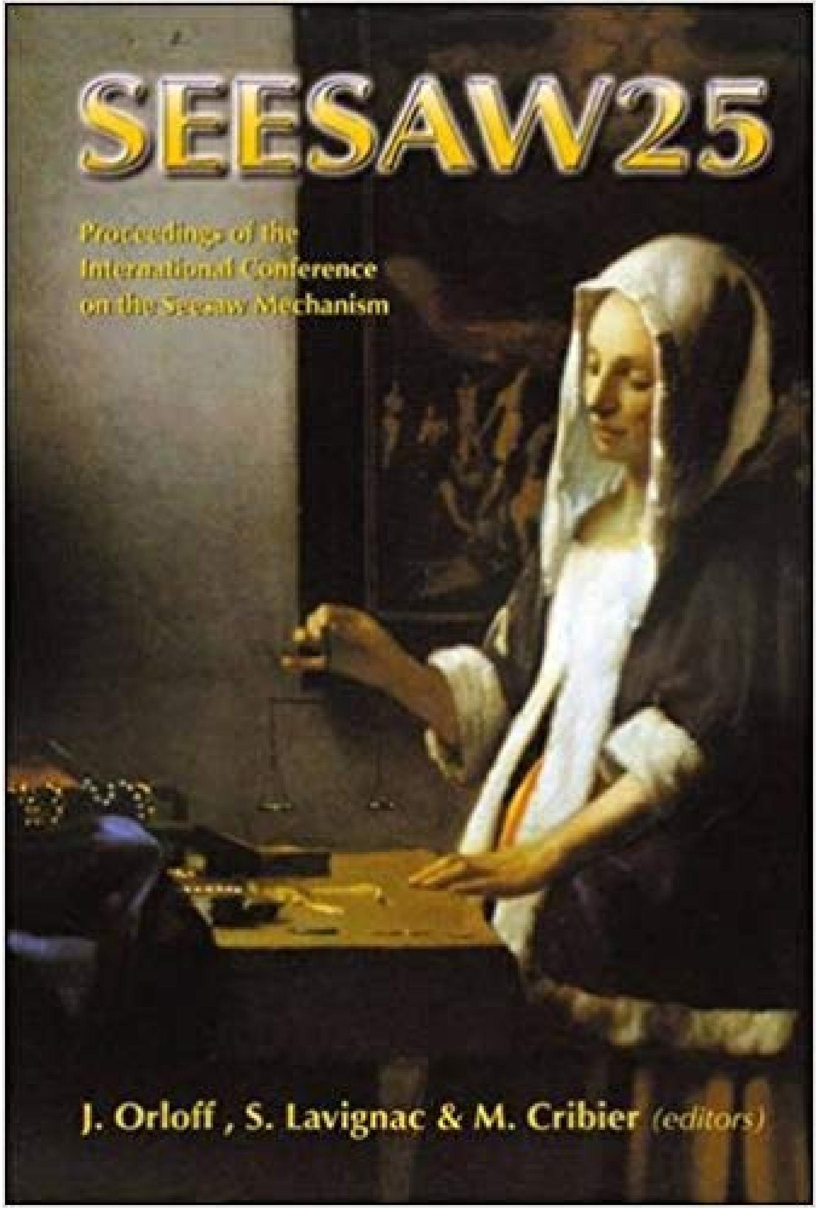
Electron neutrino appearance (evidence for 3 flavor oscillation effect).

(Of course, there are other important long baseline experiments: MINOS, OPERA, NOvA.)

Why are we so excited?

Yes, we are excited, because theorists tell us the importance of the small neutrino mass.

We are also excited, because the large mixing angles were not expected/predicted by theorists.



Future neutrino experiment in Kamioka

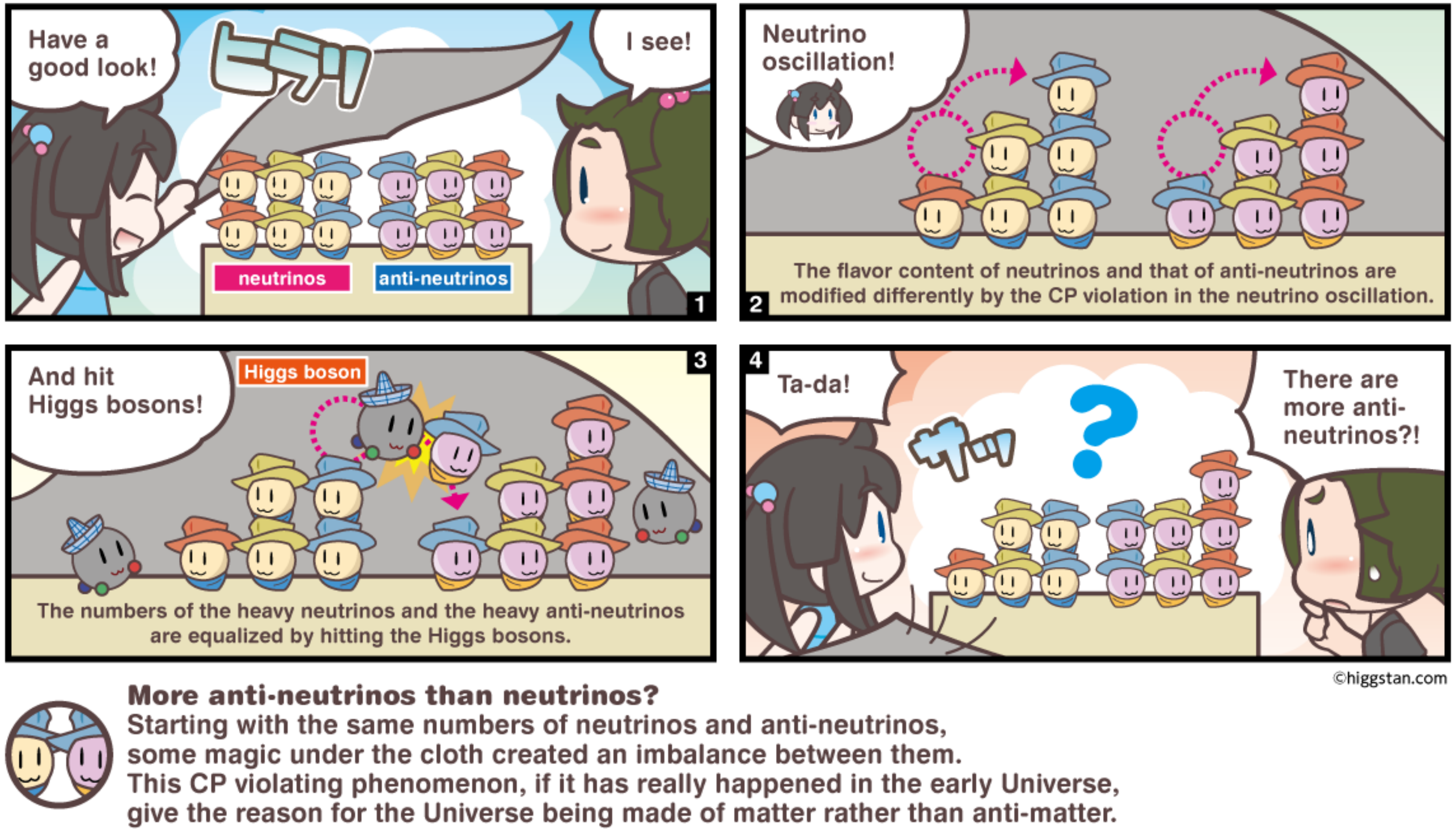
Leptogenesis

- ✓ The Baryon asymmetry in the Universe is one of the most fundamental questions in physics. We would like to know why matter particles exist in the present Universe. Small neutrino masses suggest Leptogenesis (Fukugita and Yanagida (1986)).

➔ We should check this possibility.

http://higgstan.com/4koma-leptogenesis/

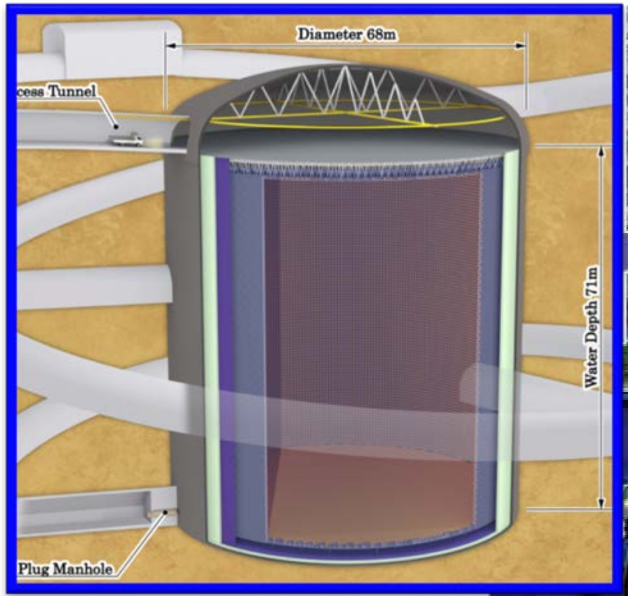
Neutrino Magic!



➔ Theoretical ideas are really very important!

Understanding the origin of the matter in the Universe

- ✓We would like to observe if oscillation of neutrinos and those of anti-neutrinos are different. If observed, it will the first step to understand the origin of the matter in the Universe.
- ✓We need the next generation neutrino experiment: Hyper-Kamiokande.

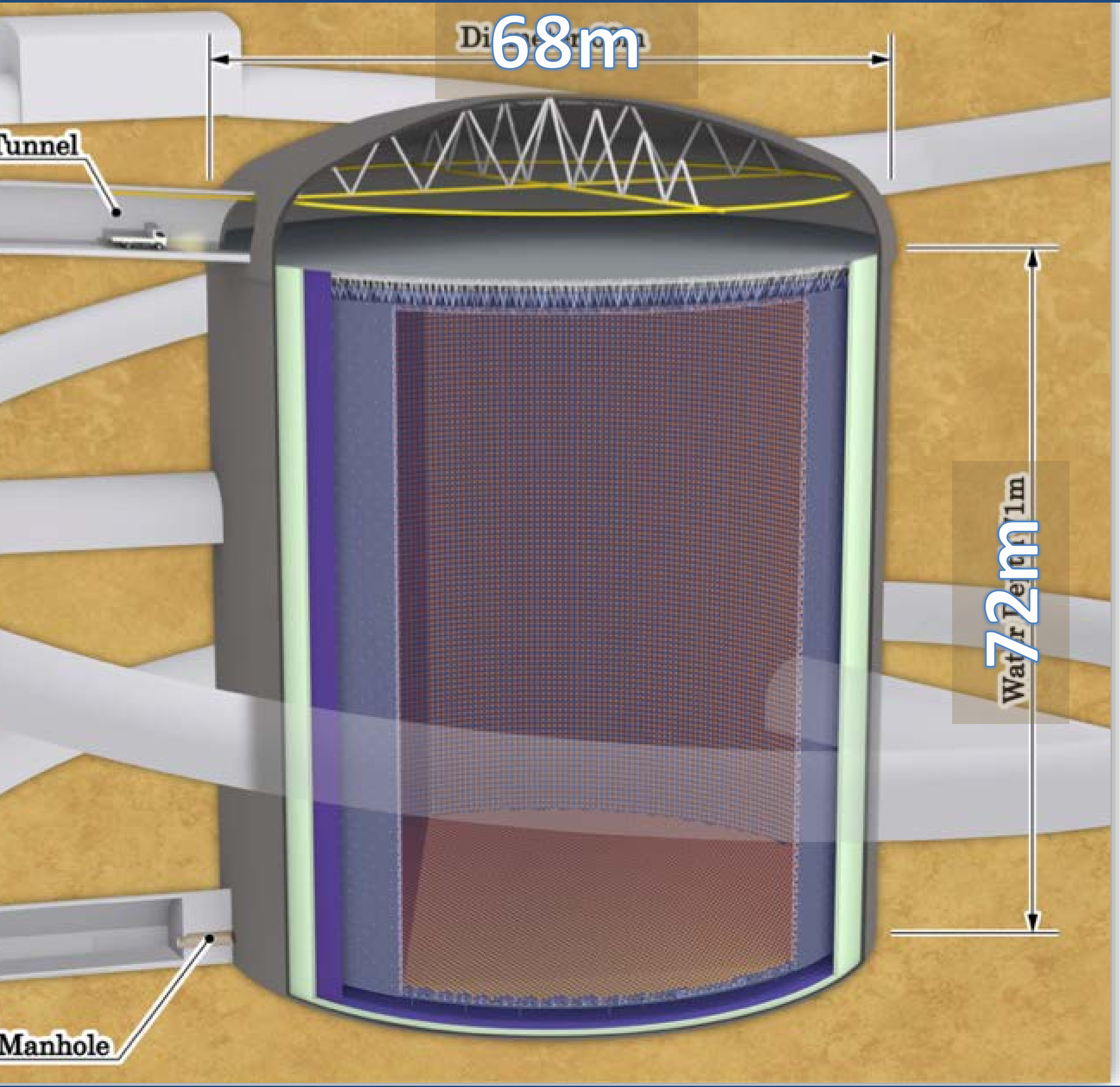


Hyper-Kamiokande

J-PARC

(Also; DUNE in USA)

Hyper-K

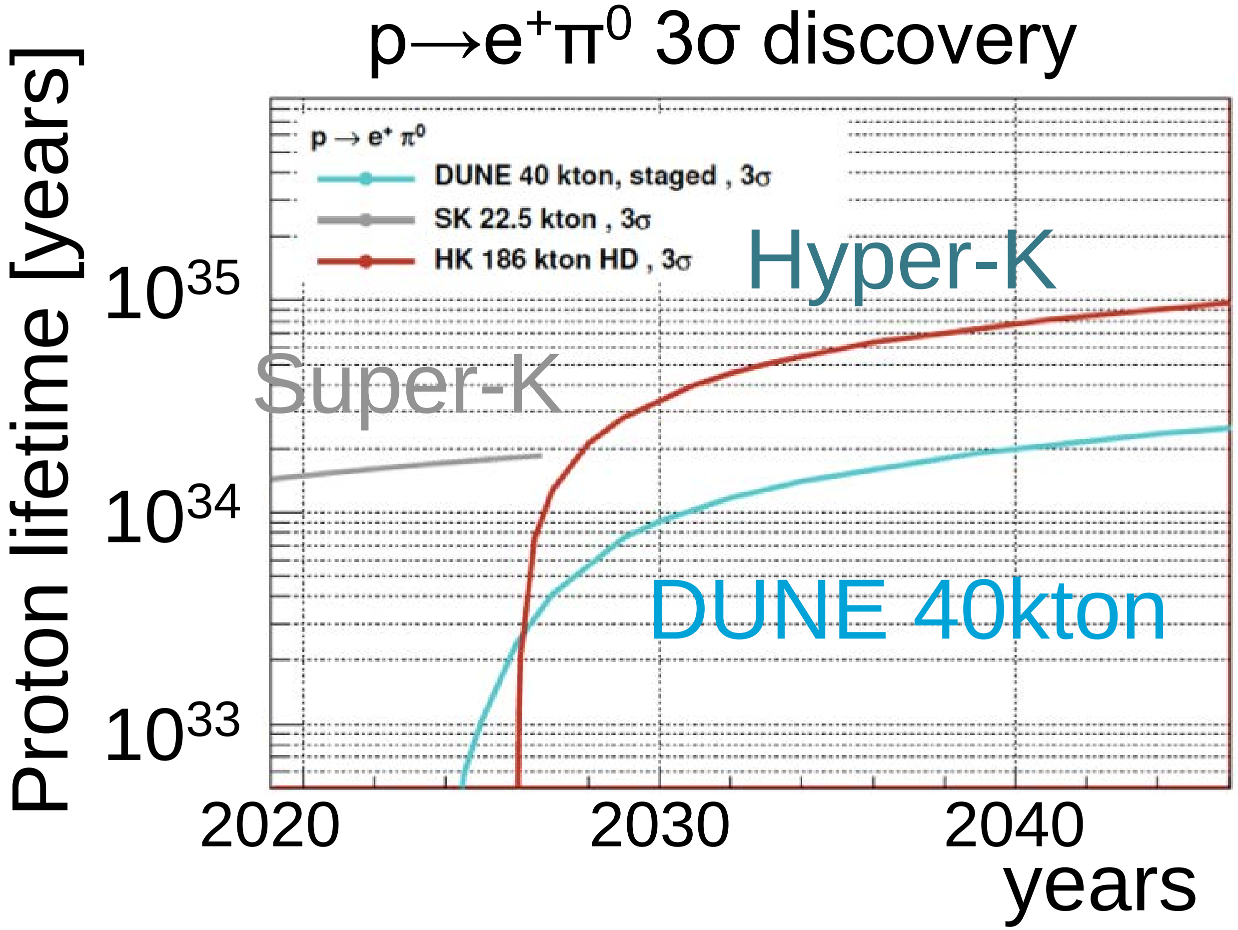


- The total and fiducial volumes are 0.26 and 0.19 M tons, respectively. (About 8 times larger than Super-K.)
- The supplementary budget for JFY2019 and the regular budget for JFY2020 include Hyper-K.
- The experiment will begin in ~2027.

Hyper-Kamiokande proto-collaboration
~340 members from 17 countries

Proton decay sensitivities

DUNE arXiv:1601.05471
HK (M. Shiozawa, Nu2018)
JUNO arXiv:1507.05613



Hyper-K 3σ discovery potential (20 years): $\tau_p < 10^{35}$ years ($e\pi^0$)

- We are still inspired by a more-than-40-year-old theoretical idea.
- Of course, we would like to hear how theorists think now.

(Lines for DUNE and JUNO experiment have been generated based on numbers in the literature.)

Summary

- Experiments in Kamioka has been (and will be) contributing to neutrino physics and astrophysics.
- Interplay of theorists and experimentalist are very important for the development of physics.