Neutrino physics, a journey from Zurich to Tokyo

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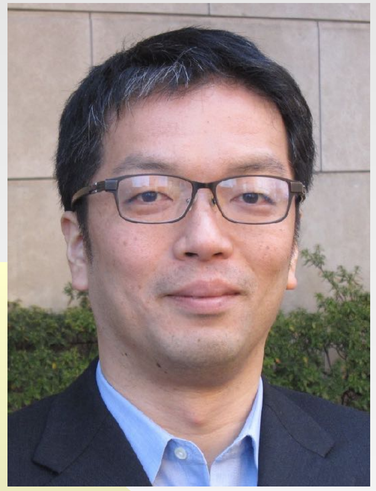
On behalf of UTokyo-ETHZ team



東京大学 大学院
理学系研究科・理学部
SCHOOL OF SCIENCE, THE UNIVERSITY OF TOKYO

It all started in Zurich, 1930

Wolfgang Pauli

ETHZ Professor at the time

Pauli's letter postulating the existence of ***neutrinos***

"Dear radioactive ladies and gentlemen, …"

Original - Photocopie of PLC 0393

Abschrift/15.12.30 PM

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst ansuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Nun handelt es sich weiter darum, welche Kräfte auf die Neutronen wirken. Das wahrscheinlichste Modell für das Neutron scheint mir aus wellenmechanischen Gründen (näheres weiss der Ueberbringer dieser Zeilen) dieses zu sein, dass das ruhende Neutron ein magnetischer Dipol von einem gewissen Moment μ ist. Die Experimente verlangen wohl, dass die ionisierende Wirkung eines solchen Neutrons nicht grösser sein kann, als die eines gamma-Strahls und darf dann μ wohl nicht grösser sein als $e \cdot (10^{-13}$ cm).

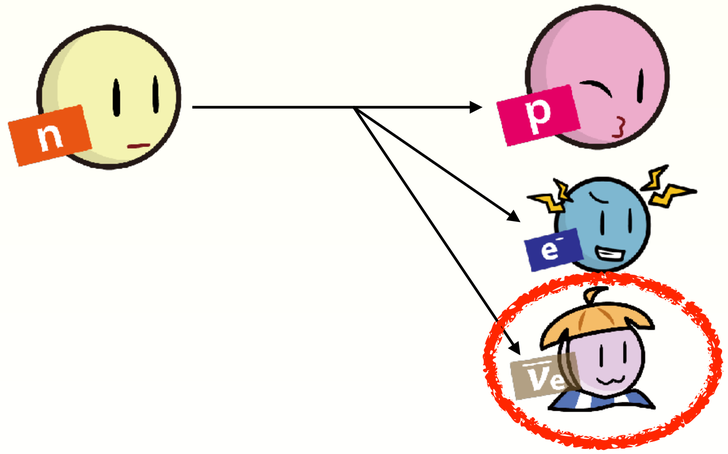
Ich traue mich vorläufig aber nicht, etwas über diese Idee zu publizieren und wende mich erst vertrauensvoll an Euch, liebe Radioaktive, mit der Frage, wie es um den experimentellen Nachweis eines solchen Neutrons stände, wenn dieses ein ebensolches oder etwa 10mal grösseres Durchdringungsvermögen besitzen würde, wie ein gamma-Strahl.

Ich gebe zu, dass mein Ausweg vielleicht von vornherein wenig wahrscheinlich erscheinen wird, weil man die Neutronen, wenn sie existieren, wohl schon längst gesehen hätte. Aber nur wer wagt, gewinnt und der Ernst der Situation beim kontinuierliche beta-Spektrum wird durch einen Ausspruch meines verehrten Vorgängers im Amte, Herrn Debye, beleuchtet, der mir kürzlich in Brüssel gesagt hat: "O, daran soll man am besten gar nicht denken, sowie an die neuen Steuern." Darum soll man jeden Weg zur Rettung ernstlich diskutieren.- Also, liebe Radioaktive, prüfet, und richtet.- Leider kann ich nicht persönlich in Tübingen erscheinen, da ich infolge eines in der Nacht vom 6. zum 7 Dez. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

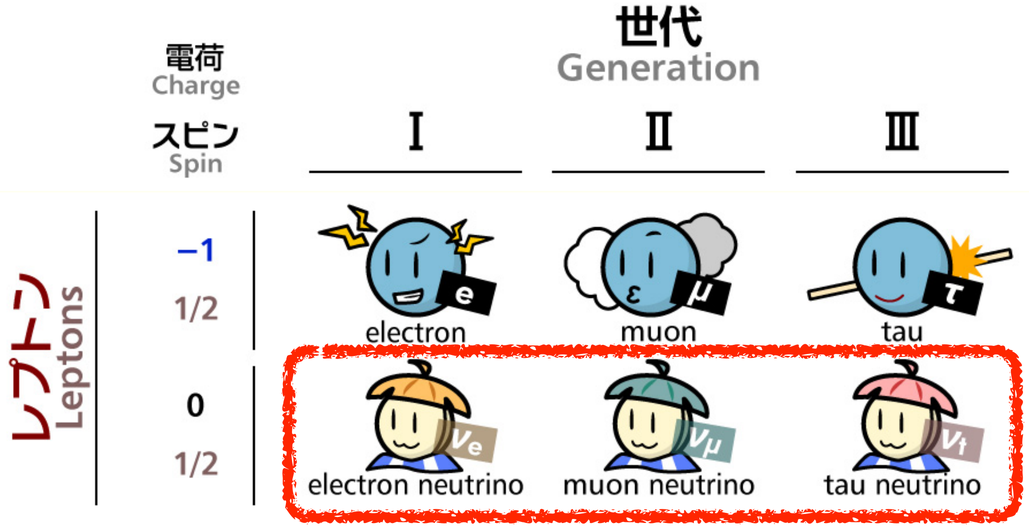
gez. W. Pauli

Image: higgstan.com

Explaining beta decay



Neutrinos — neutral and tiny

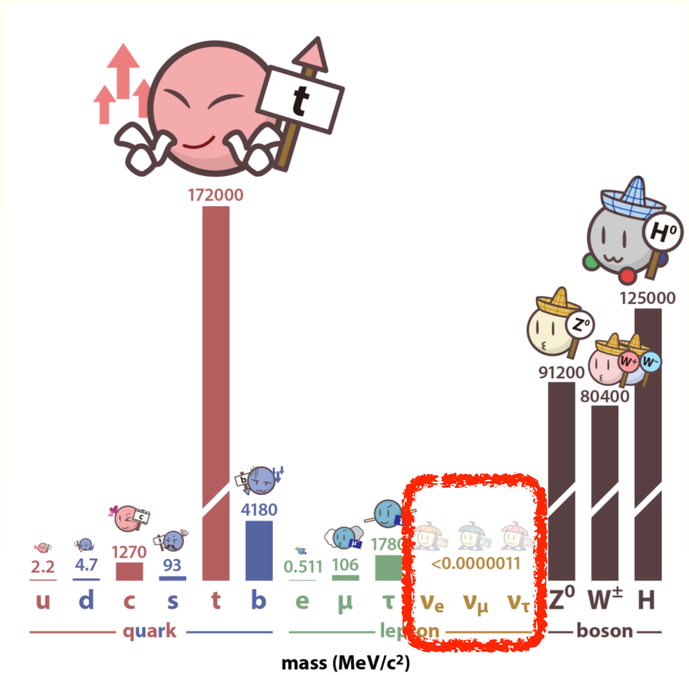


There are 3 types (“flavors”) of neutrinos

- Cousins of electrons, but electrically neutral

- Only interact with “*weak* interaction” of elementary particles
  — can path through the earth easily
  mean free path ~100 light years
  for neutrinos from Sun

Akimoto,

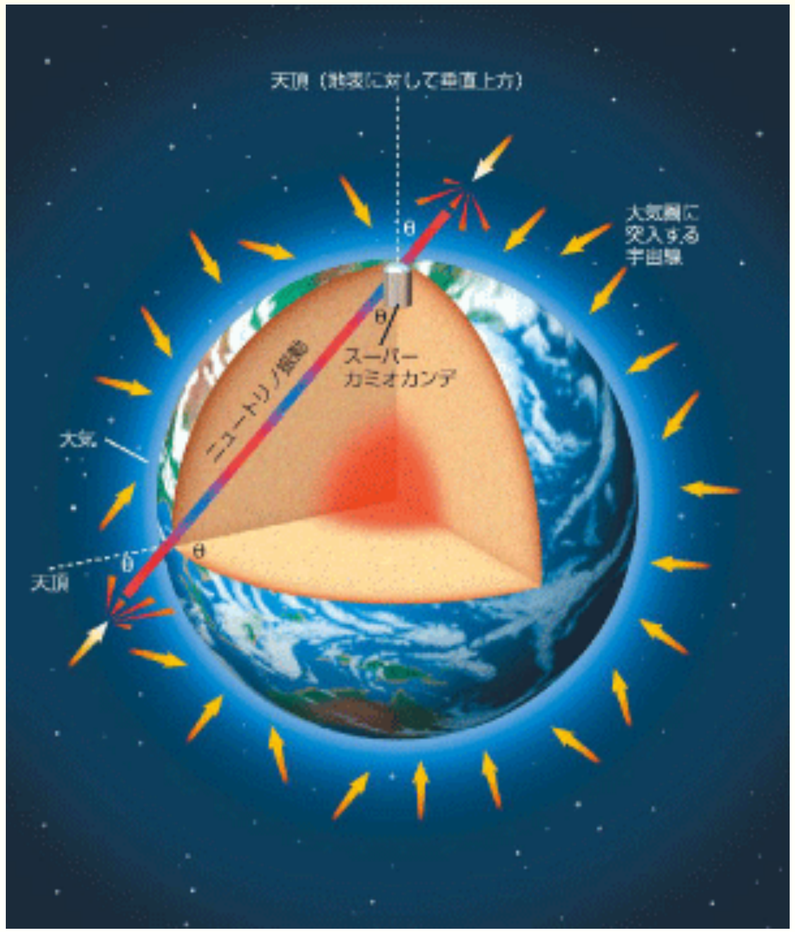


- Mass is ≲1 millionth of electrons (the 2nd lightest)
  — believed to be *massless* until 1998

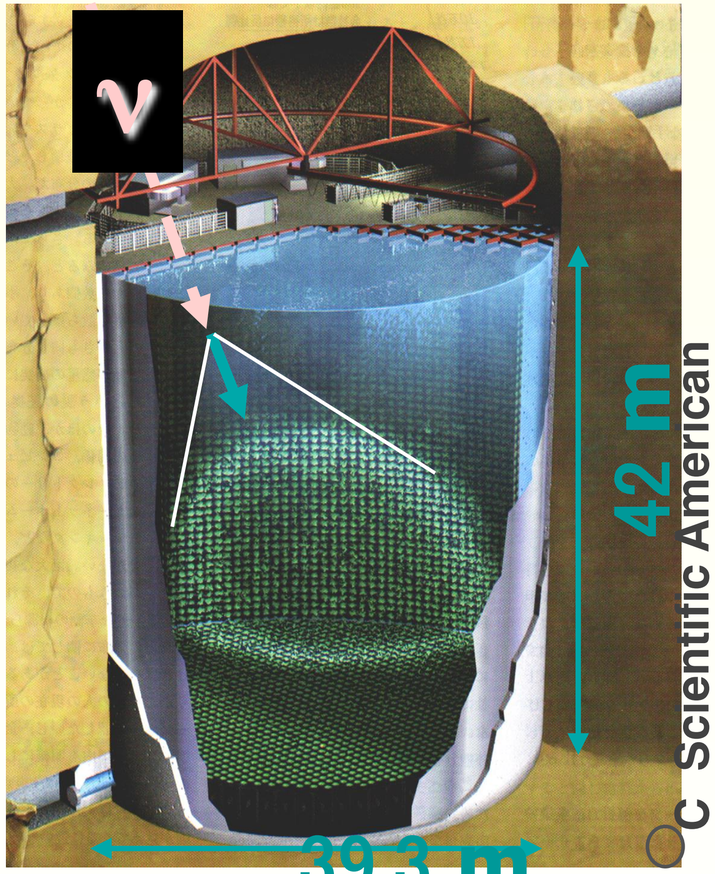
Image: higgstan.com

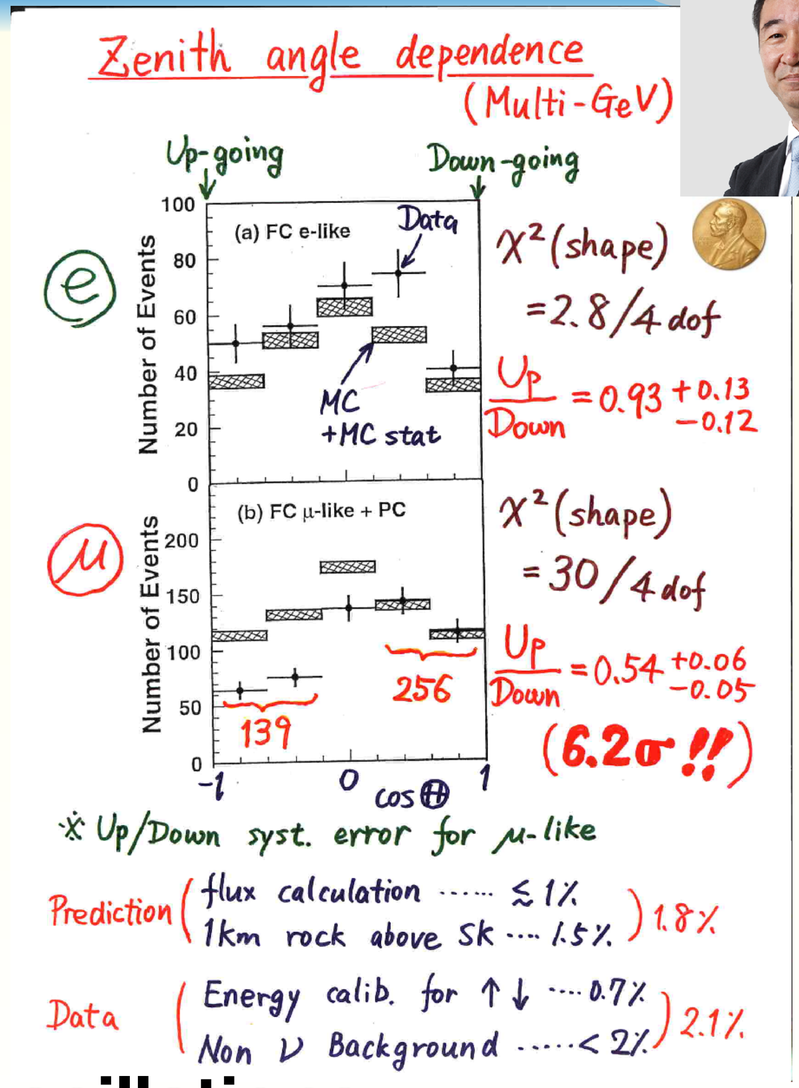
In Japan, 1998

Atmospheric neutrinos



Super-Kamiokande detector
hosted by **UTokyo**



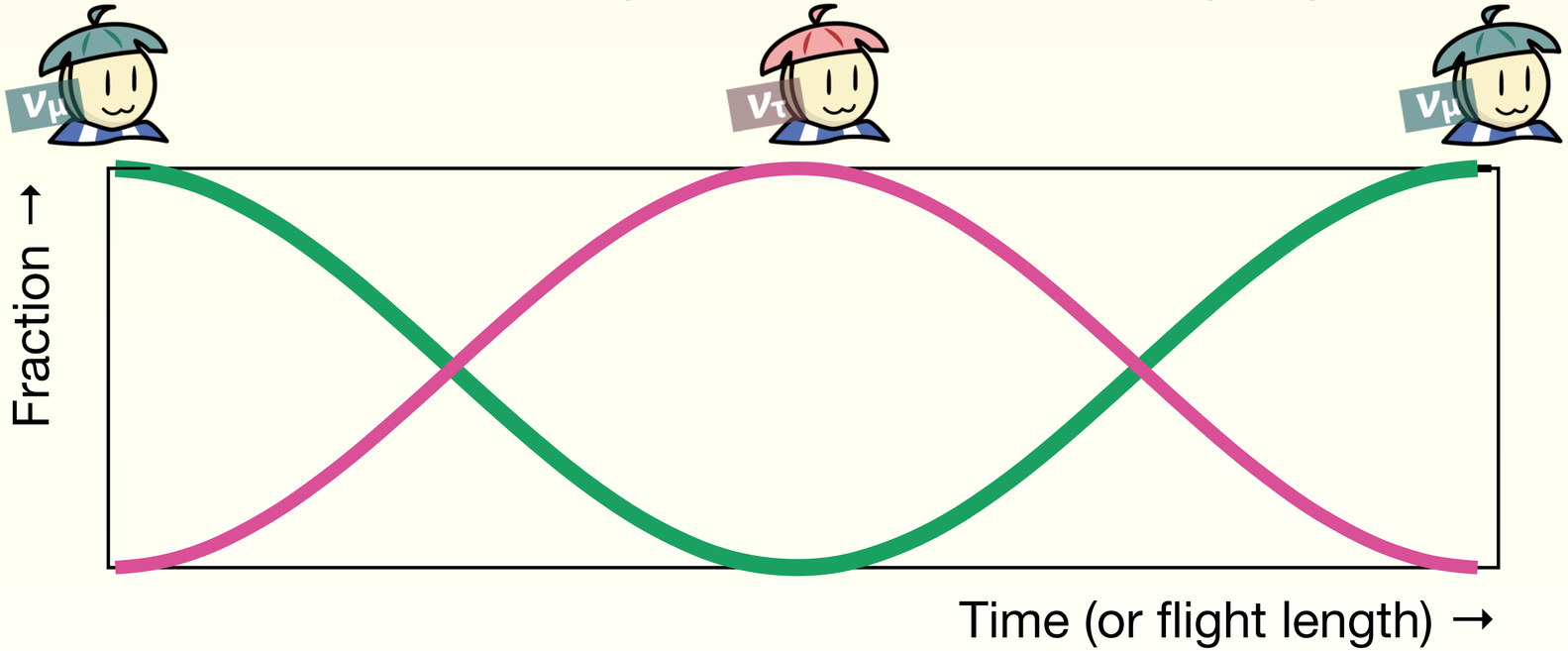


2015

The first firm evidence for **neutrino oscillations,**
which shows that neutrinos have mass

Neutrino oscillations

Neutrinos change their flavors during flight



The probability of flavor change is (case of 2 types for simplicity)

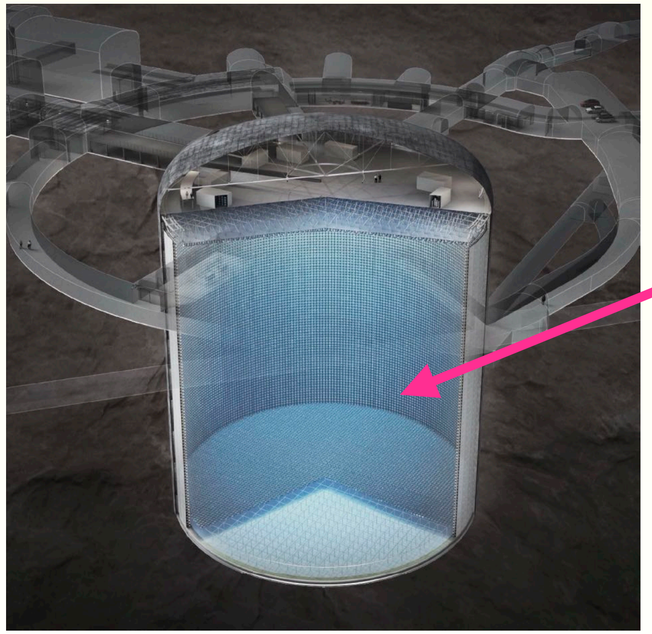
$$\sin^2(2\theta)\sin^2\left(\Delta m^2 \times \frac{L}{E}\right)$$

θ: “mixing angle” between flavors
Δm^2: mass-squared difference, m_2^2-m_1^2
L: flight distance
E: energy of neutrino

Properties of neutrinos can be studied by measuring neutrino oscillations

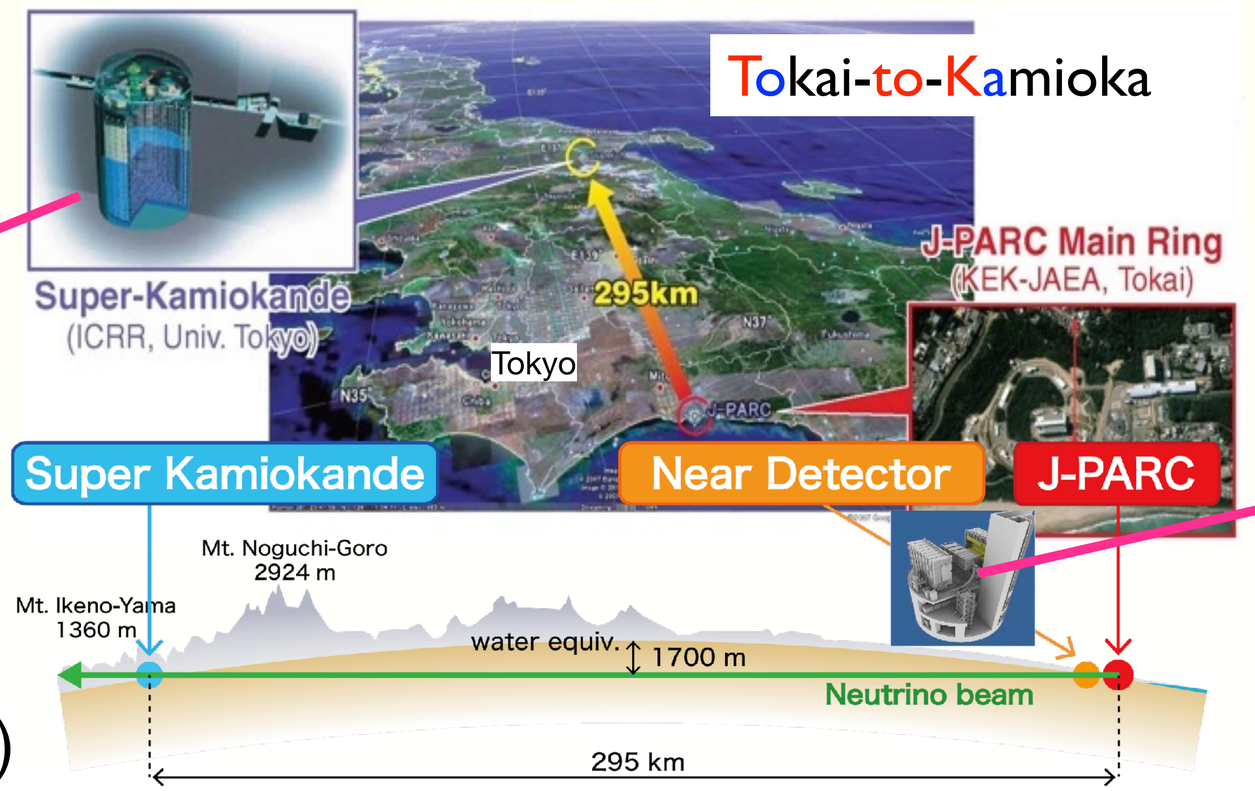
Experiments with artificial neutrino beam

- Sending a neutrino beam from J-PARC accelerator to Kamioka, 295km away
  - Better precision with controlled neutrino source (known L and E)
  - Reduction of uncertainties by measuring neutrinos before oscillation with near detectors
  - Select neutrino or anti-neutrino by changing setting (polarity of electromagnets)

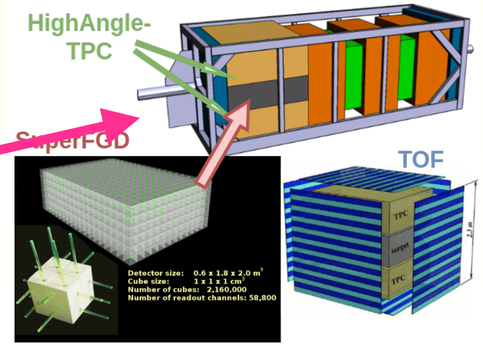


Hyper-Kamiokande
(under construction, 2027-)

T2K experiment in Japan

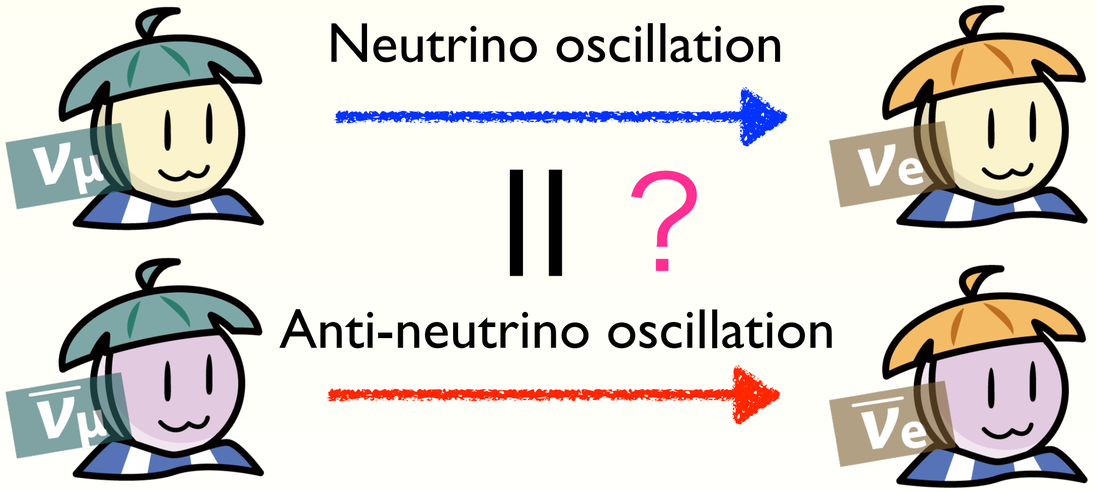


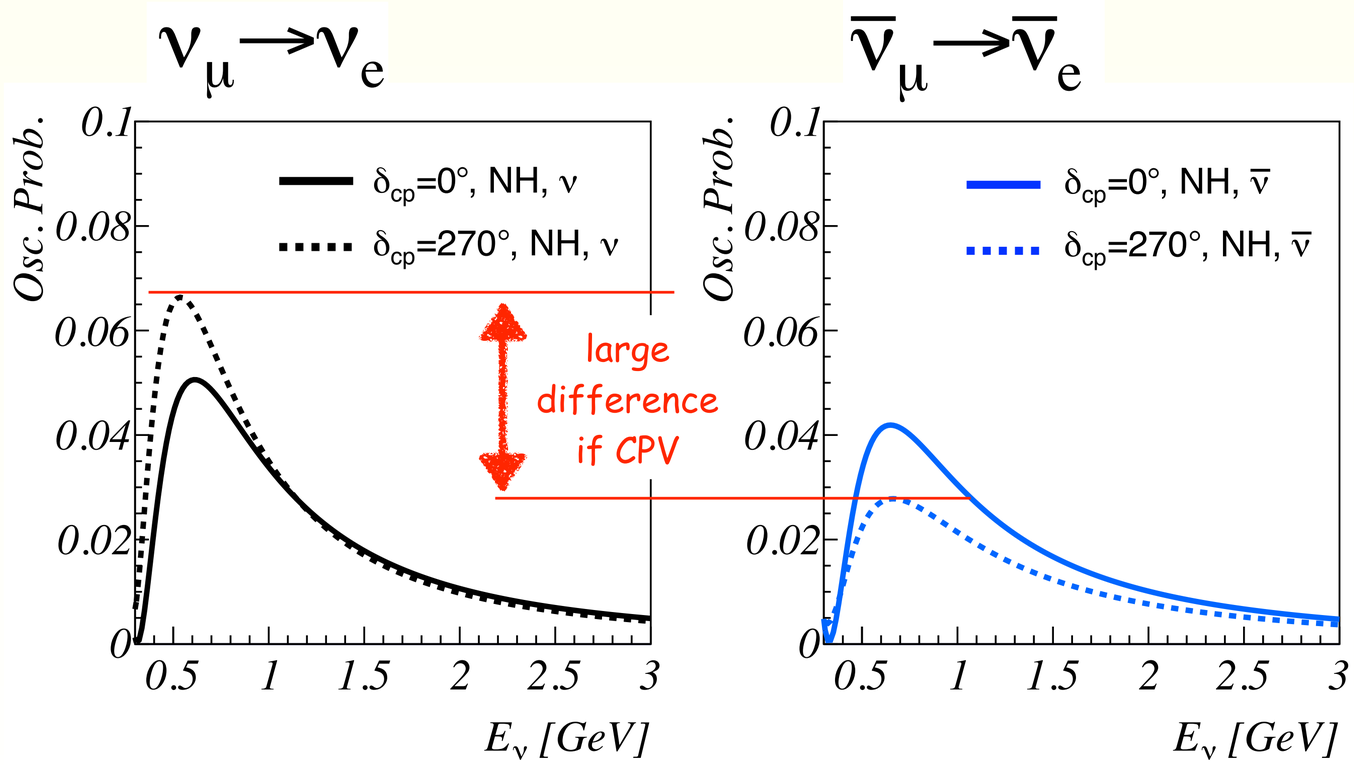
Near Detector Upgrade (2023)



Matter-antimatter asymmetry in neutrinos

- CP (Charge conjugation + Parity): fundamental symmetry between particles and anti-particles
- **CP violation**: One of necessary conditions to explain the baryon asymmetry in Universe (Sakharov)
  - Known in quarks (Kobayashi-Maskawa), not yet observed in leptons
  - Introduced by a complex phase δ_{CP} (CP violation if $\sin\delta_{CP}\neq 0$)
- Can be studied by a comparison of $\nu_\mu \rightarrow \nu_e$ appearance probabilities between neutrinos and anti-neutrinos

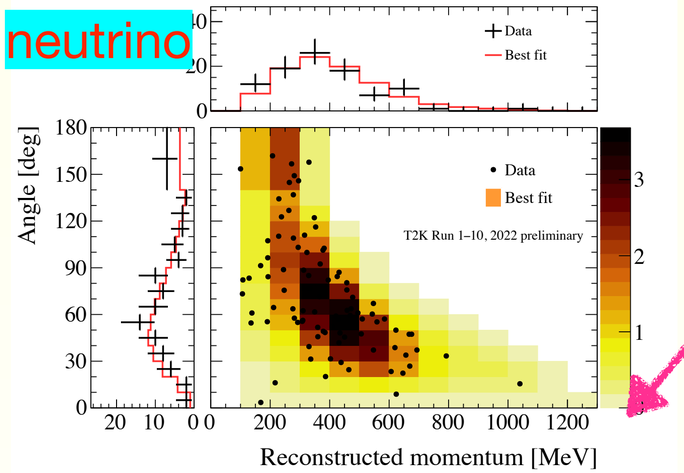




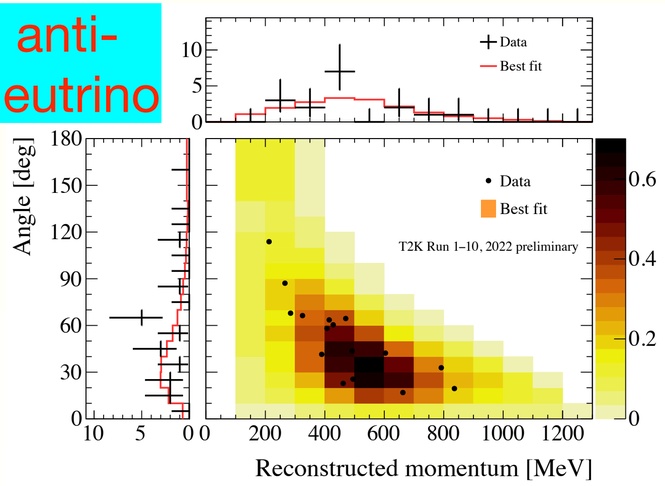
CP violation search: latest results

Electron-neutrino candidates observed at Super-Kamiokande

neutrino

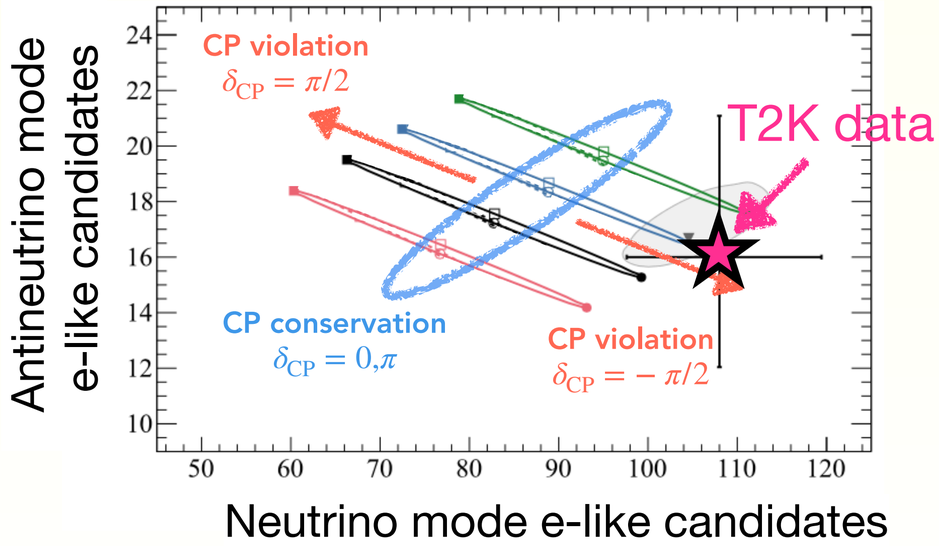


anti-neutrino

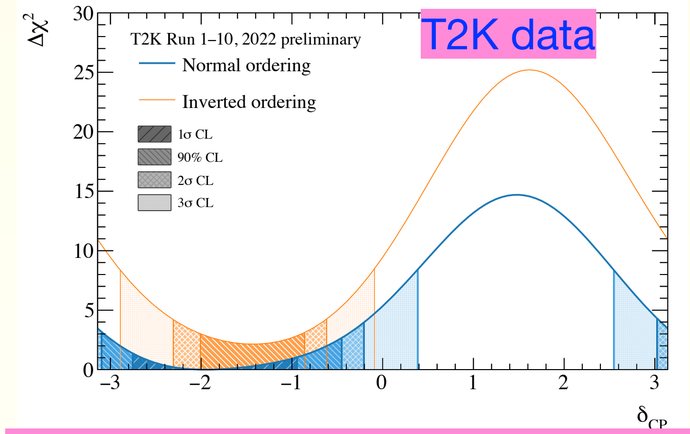


- Neutrino beam flux estimation
- Near detector measurements
- Neutrino interaction models
- 6 samples from far detector (Super-Kamiokade)

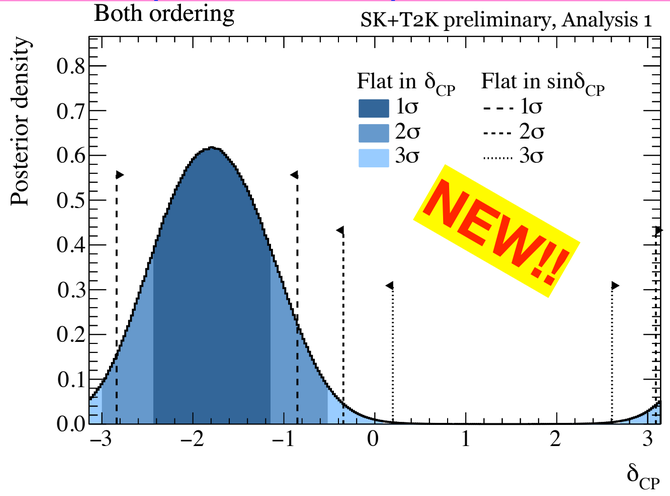
T2K data favors large CP violation



CP conservation (δ_{CP}=0,π) outside of 90% CL region



T2K + Super-K atmospheric neutrinos

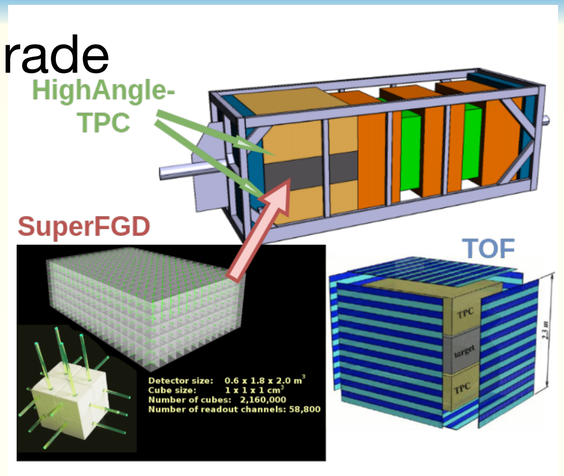


First hint of CP violation in the lepton sector

→ Further study with more data and less uncertainties

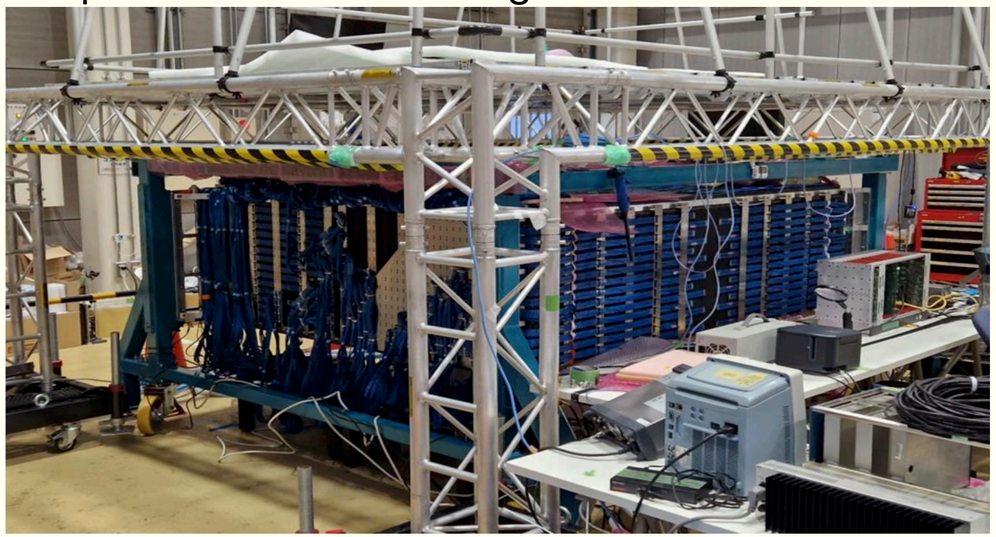
Near Detector Upgrade for more capability

Near Detector Upgrade
(CERN NP-07)

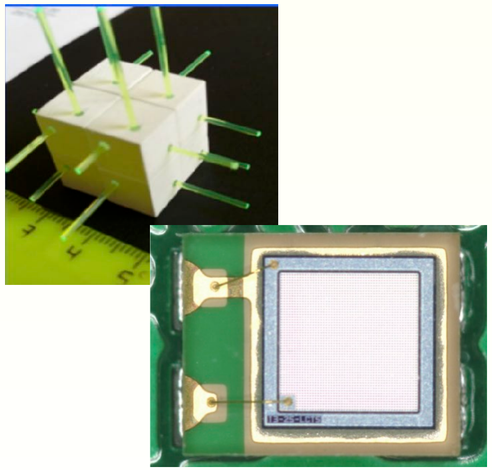


D.Sgalaberna(ETHZ):
proposal of SuperFGD
group co-convener

SuperFGD commissioning at J-PARC

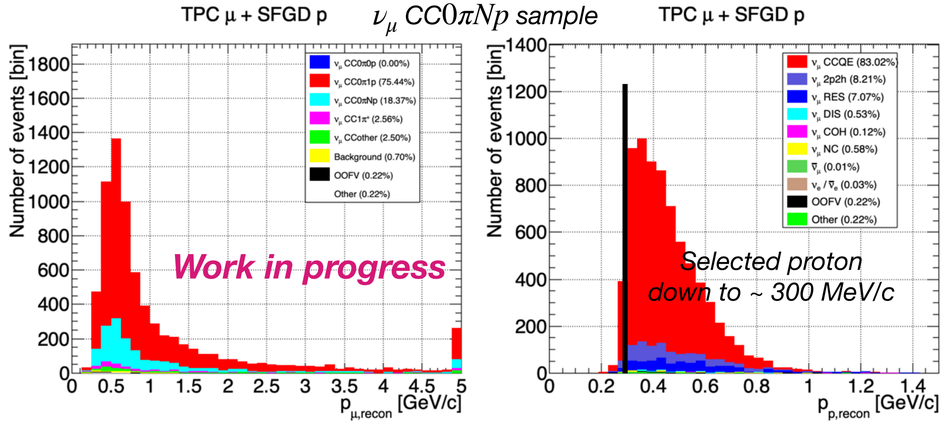


**Central part: Super Fine-Grained Detector (SuperFGD)
consisting of 2,000,000 plastic scintillator cubes**



Photon detection with MPPC®
(Hamamatsu Photonics)
~56,000 channels

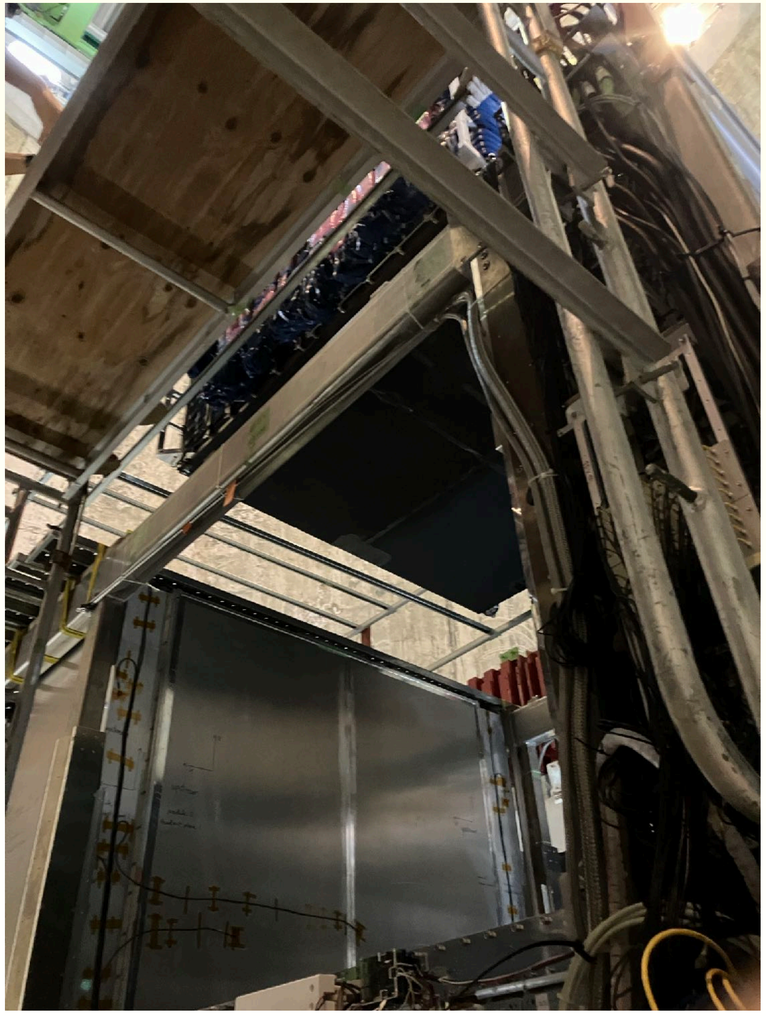
Reconstruction and analysis of ND data

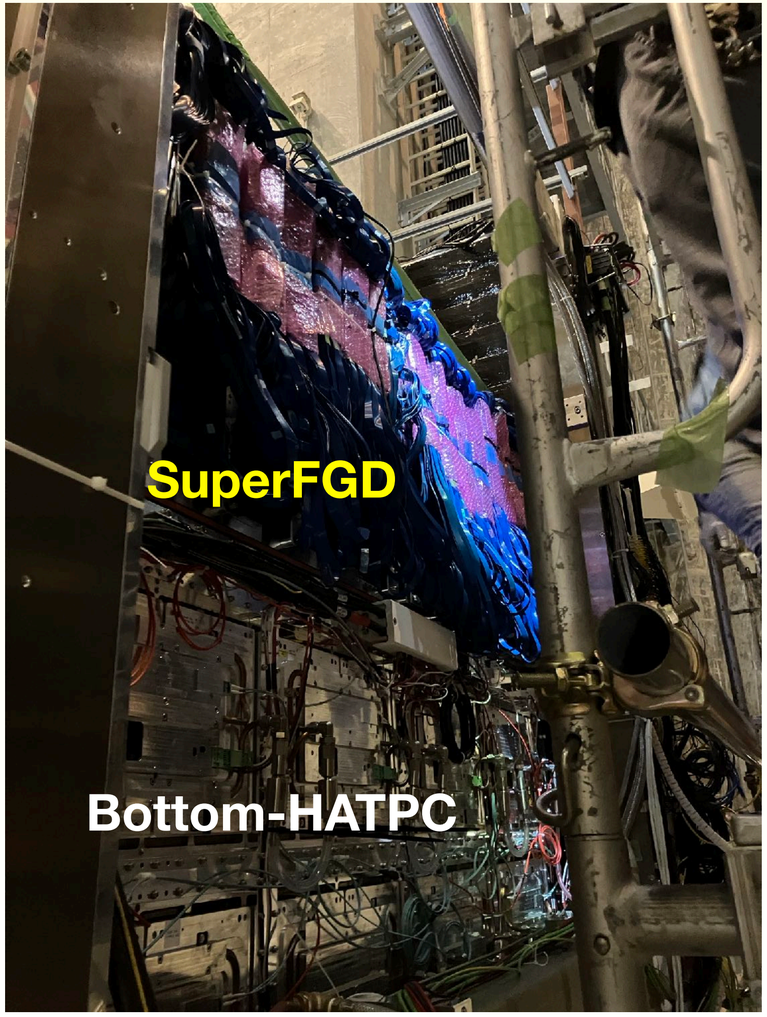


+ Development towards Near Detectors for Hyper-Kamiokande

SuperFGD detector installed in the basket

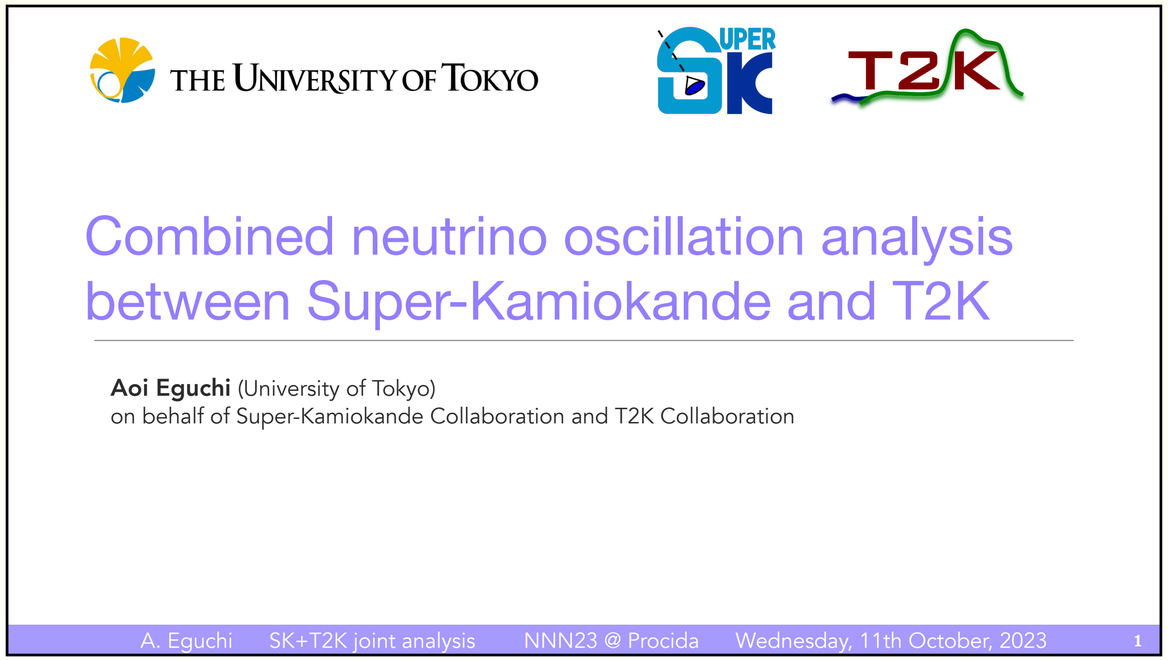
October 12, 2023





Ph.D students just gave talks at an international conference last week

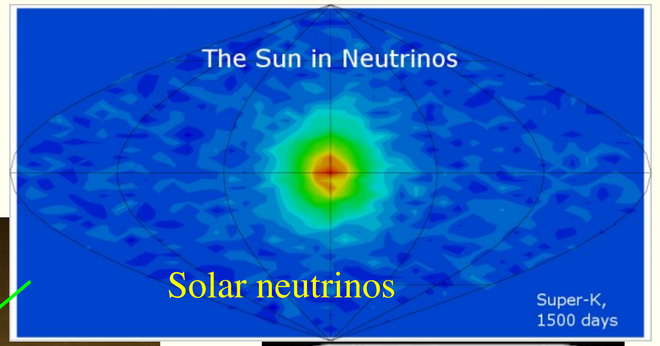
X.Zhao (ETHZ)

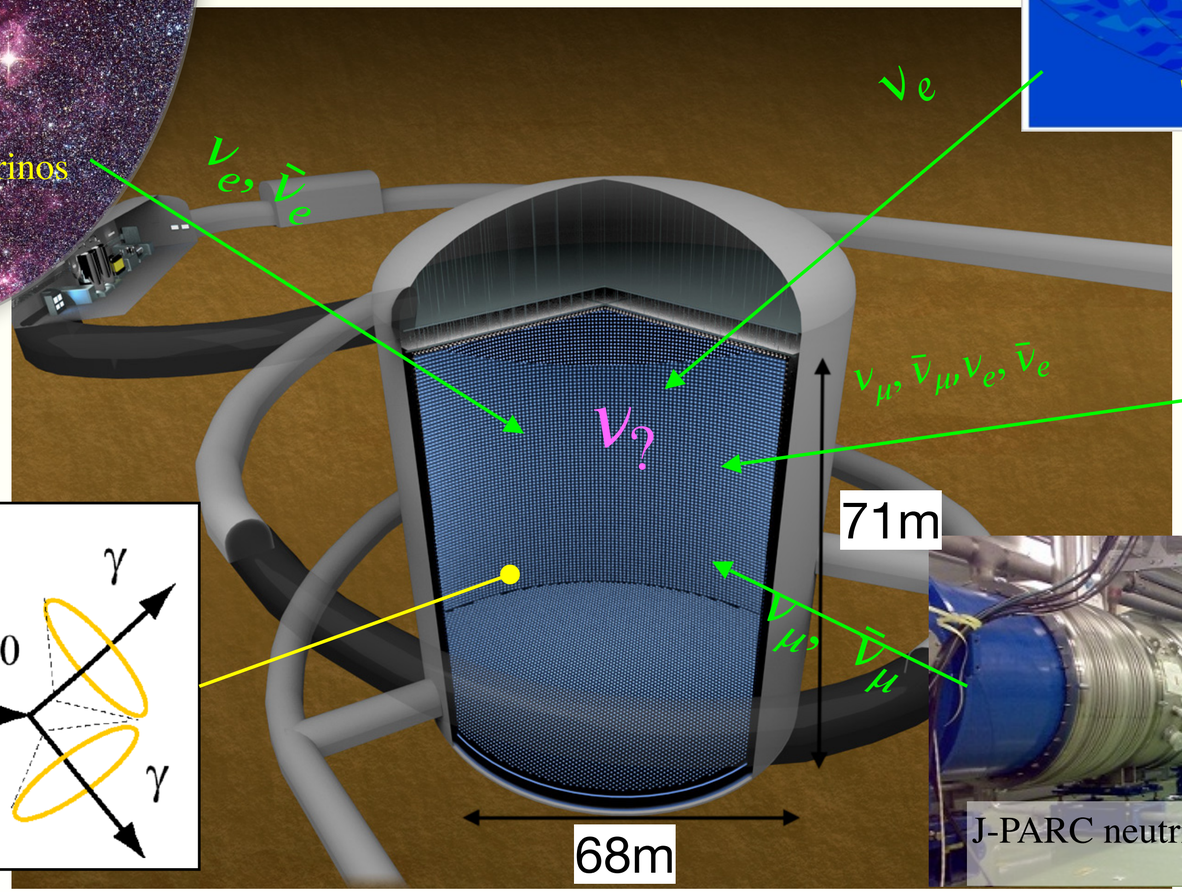


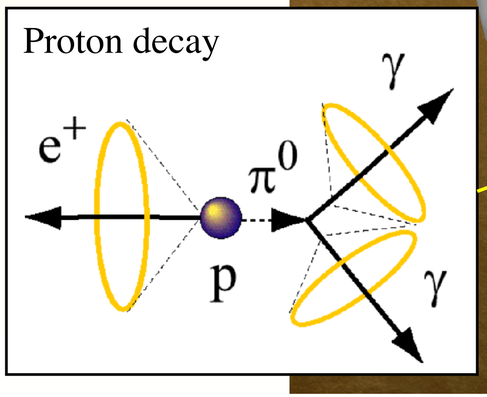
A.Eguchi (U.Tokyo)

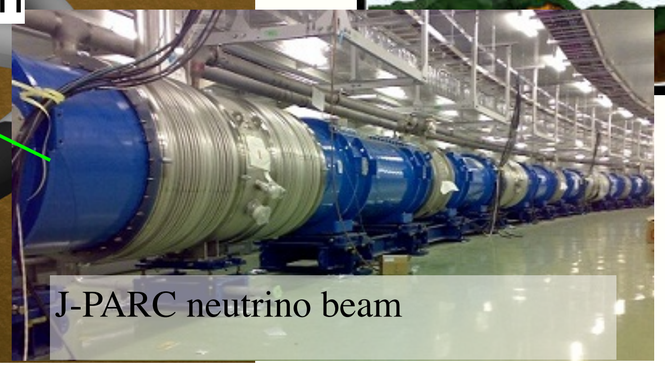
Next generation: Hyper-Kamiokande

260kton total water mass
190kton fiducial mass
(Super-K: 22.5kton)



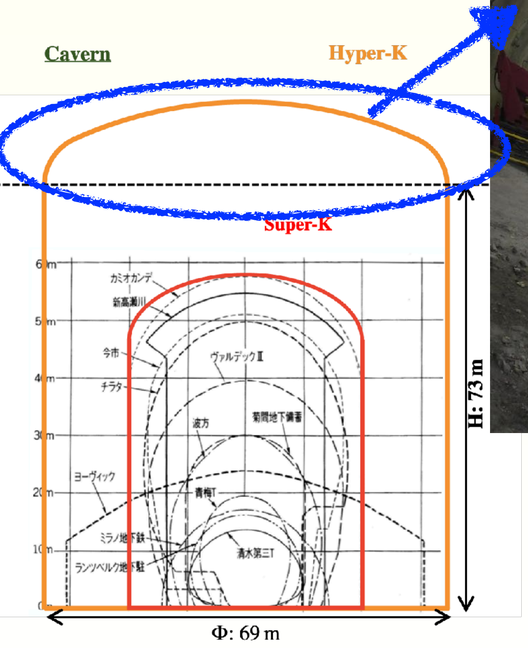






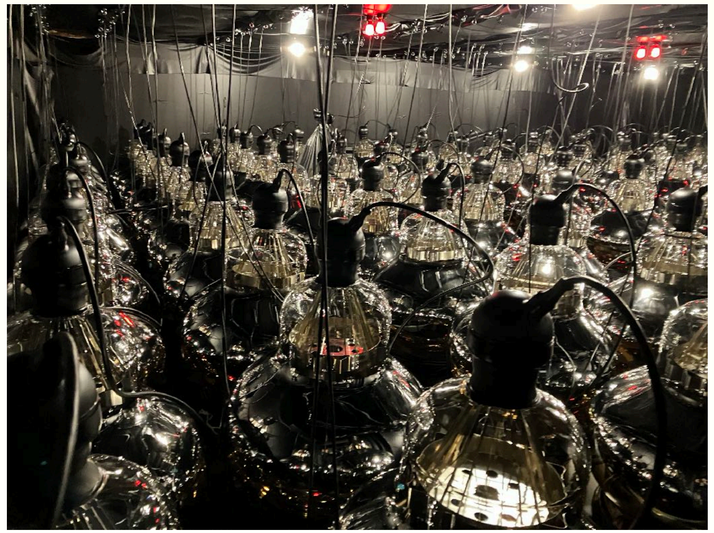
Status of construction

Completion of the dome section (69m dia., 21m height) Oct.3, 2023



(ICRR, University of Tokyo)

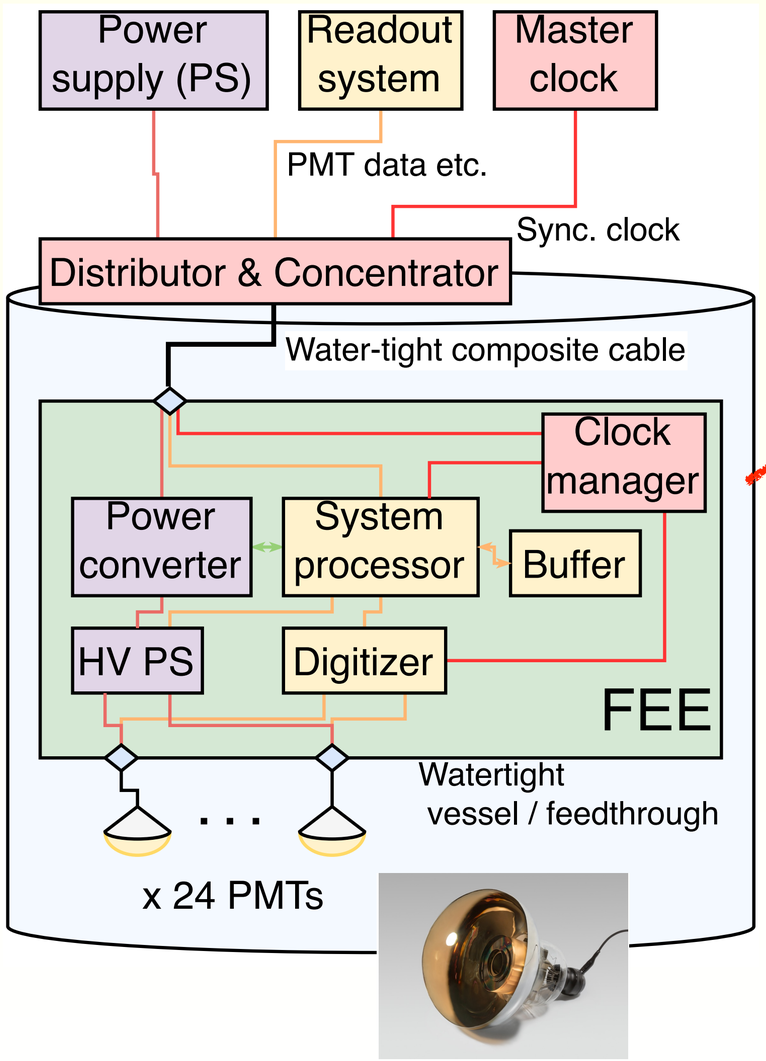
Delivery and test of 50cm diameter photomultiplier tubes (PMTs) produced by Hamamatsu Photonics

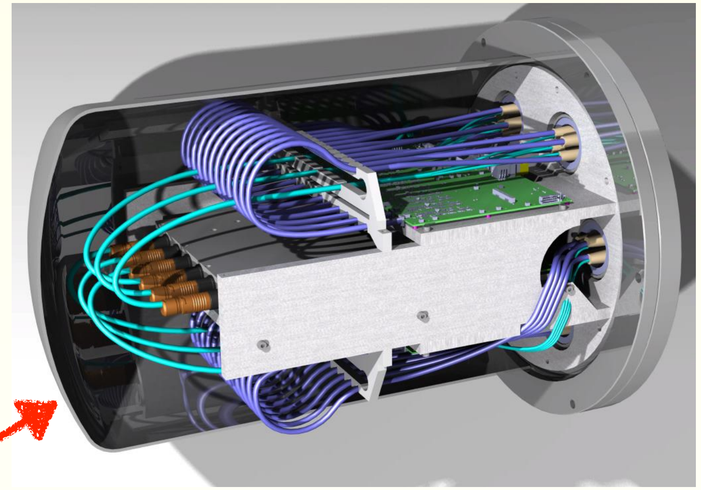


>6,000 PMTs already delivered

Underwater electronics for Hyper-K

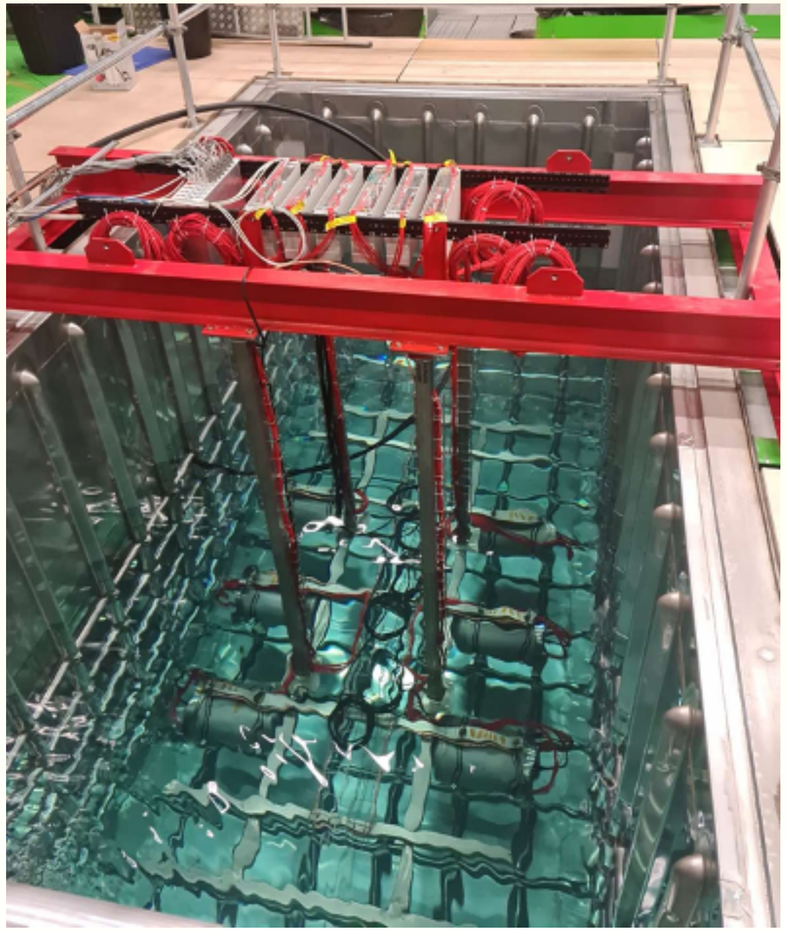
Overall coordination: Y.Hayato (ICRR, U.Tokyo)





Key contributions by ETHZ:

- Design, production, test of watertight vessels and power supplies (LV/HV)
- Management of integration and test at CERN



Summary

- Starting in 1930 (Pauli), neutrinos have been guiding us to better understanding of elementary particles and our universe
- First evidence for neutrino oscillations (1998) by Super-Kamiokande, hosted by UTokyo, opened a new road for fundamental research
- Now we have the first sign of CP violation in neutrino oscillations
- Further progress expected by upgraded T2K and Hyper-Kamiokande
- ETHZ-UTokyo collaboration has been playing leading roles in this field, we will continue the journey together!