T2K Experiment & VN-neutrino Group

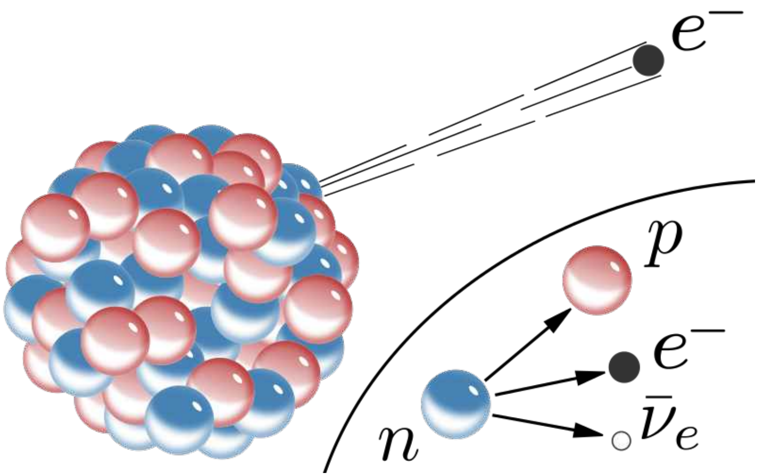
Nguyen Minh Truong
Da Nang university of science and technology (DUT)

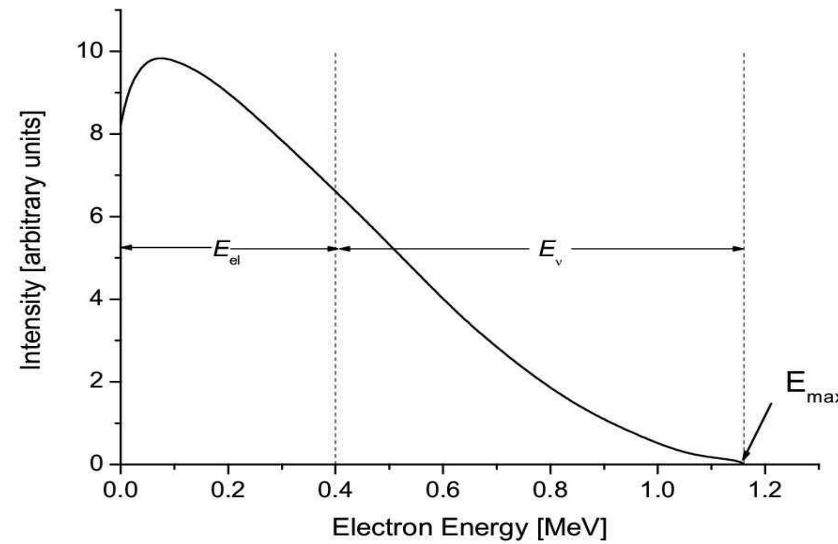
HCM – Nov 21, 2017

Content

- Neutrino Introduction
- CP Violation
- T2K Experiment
- VN-neutrino Group

Neutrino Introduction





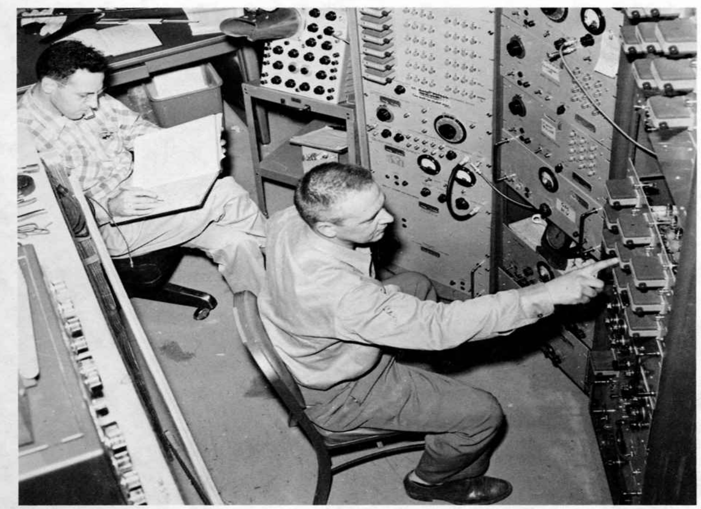
- 1914~1930, energy conservation in β decays went crisis
- 1930, W. Pauli postulated a new *"invisible"* particle

"I have done a terrible thing. I invented a particle that cannot be detected"

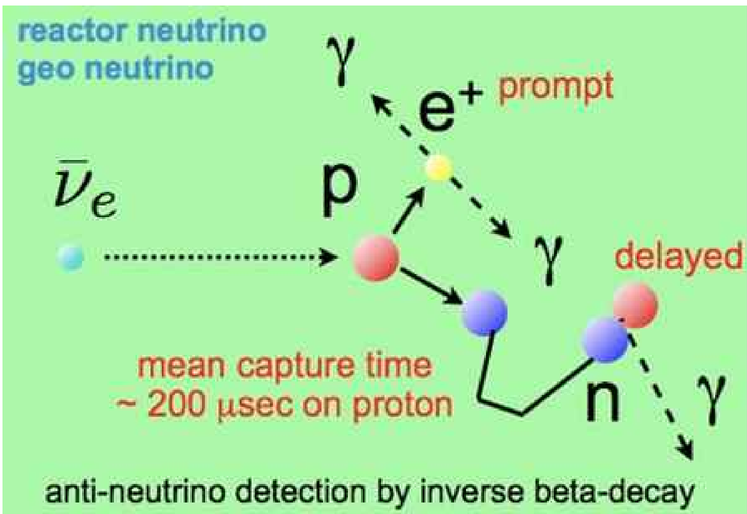
– W. Pauli

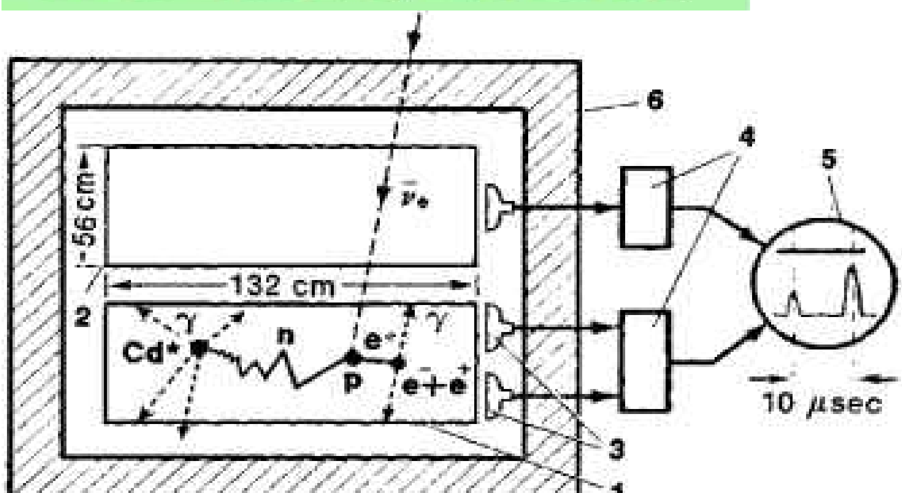
Neutrino: First Discovery in Lab

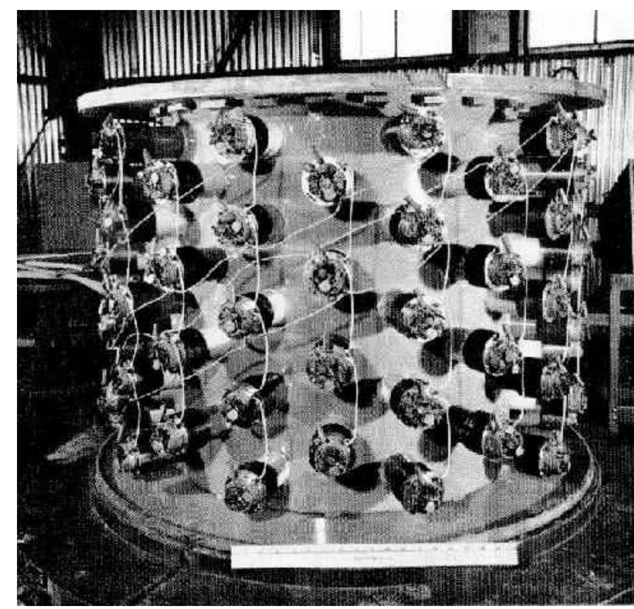
- 1933, E. Fermi built weak interaction theory of neutrinos
- 1956, Reines & Cowan, first detected (anti-)neutrino experimentally
  → Nobel prize in 1995



Frederick Reines (left) and Clyde L. Cowan, Jr. with the control equipment used in their first tentative observations of the neutrino at Hanford, Washington, in 1953. Their definitive detection of the (anti) neutrino was performed at Savannah River, Georgia, three years later. (Courtesy General Electric Co.)

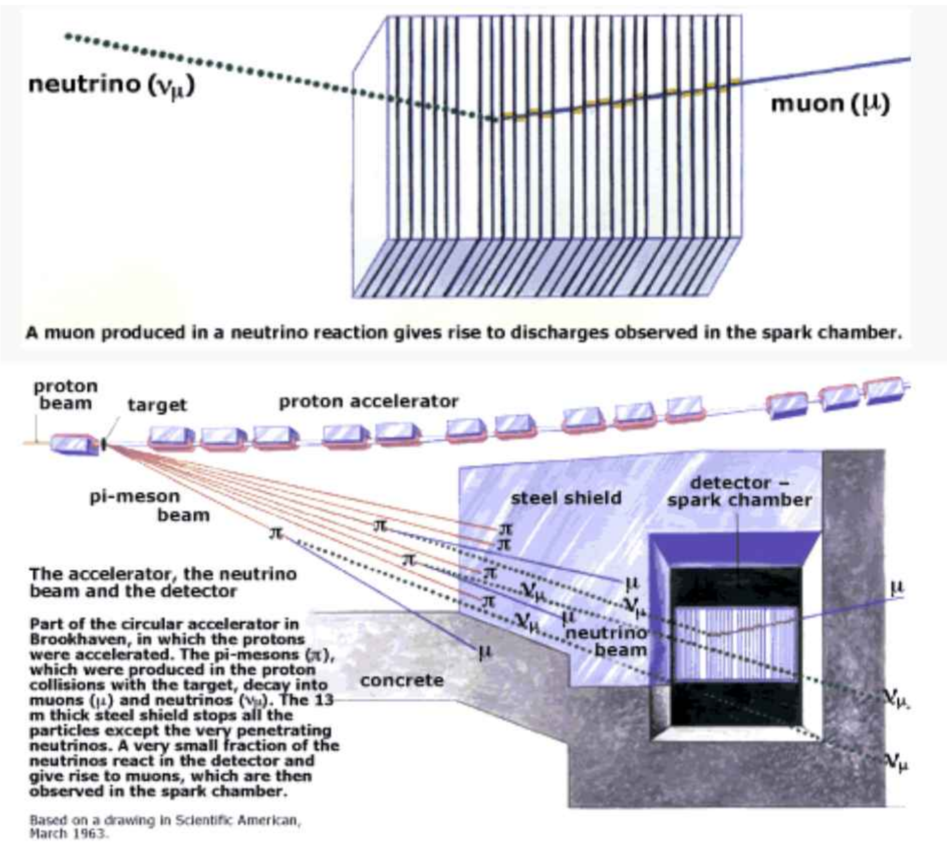




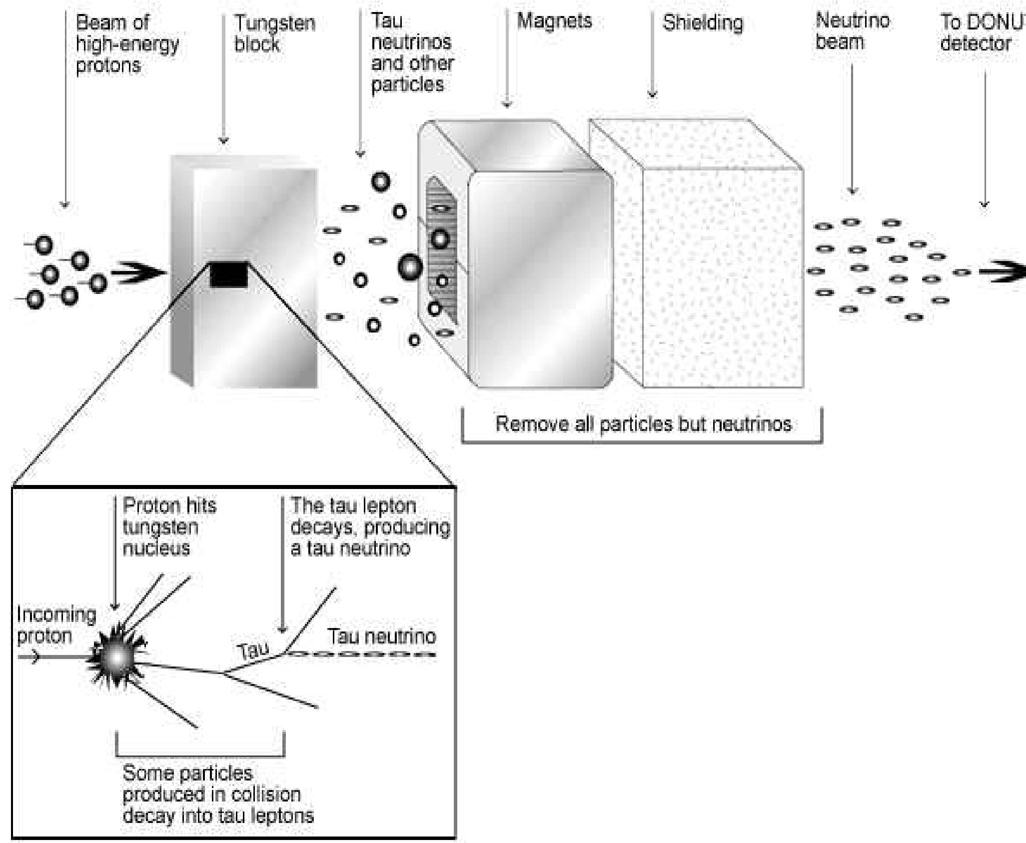


Three Types of Neutrino

Muon neutrino (ν_μ)



Tau neutrino (ν_τ)

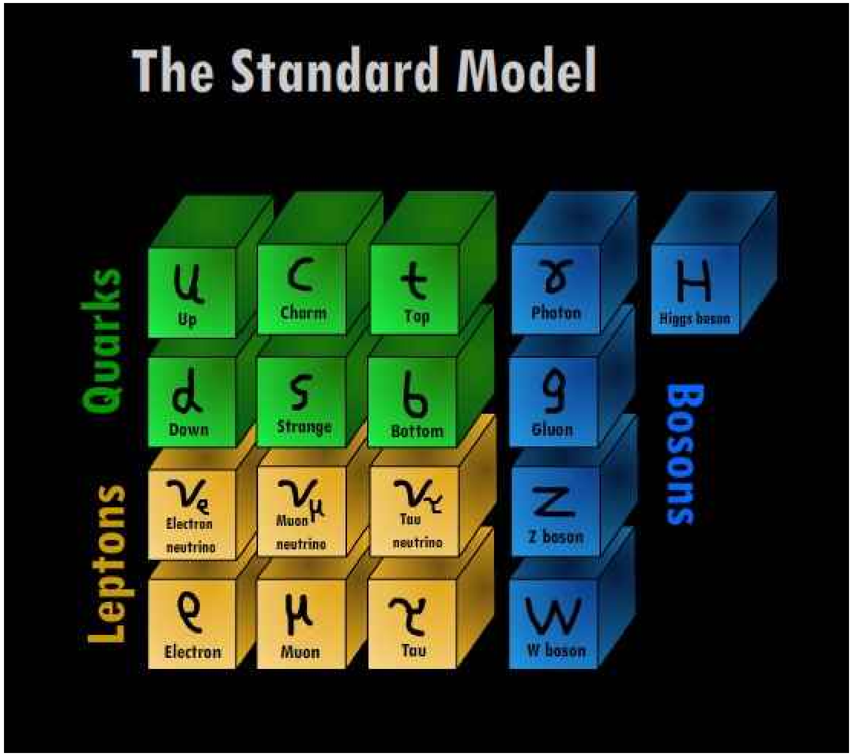


Nobel Prize 1988

Neutrino: undetect particle → detectable

Neutrino in Standard Model

Standard Model:



* neutrinos have zero mass

* three type of neutrinos ν_e, ν_μ, ν_τ,
  & belong to lepton families
  (e, ν_e), (μ, ν_μ), (τ, ν_τ);

* neutrinos and antineutrinos are distinct;

* all neutrinos are left-handed
  & all antineutrinos are right-handed.

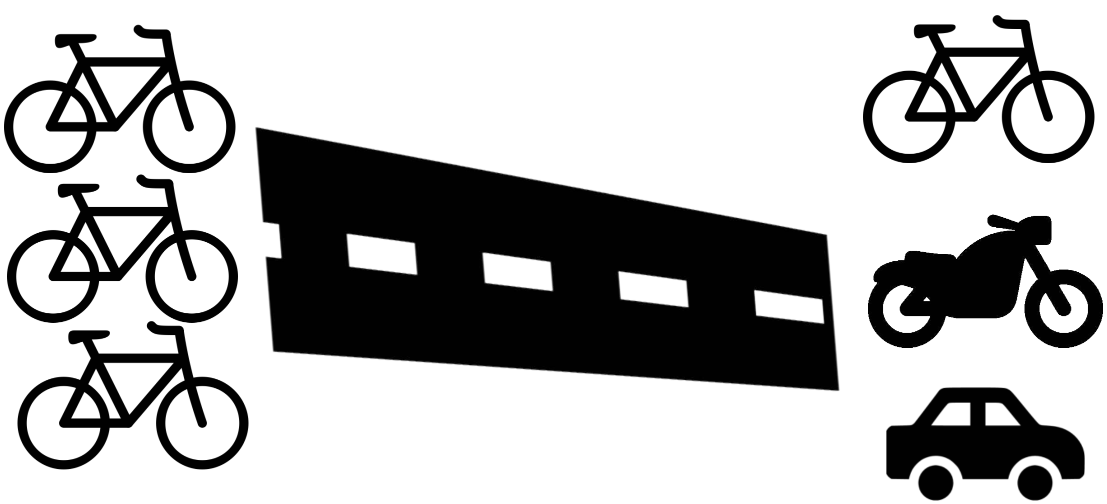
Neutrino Oscillation

a quantum mechanical phenomenon whereby a neutrino created with a specific lepton flavor (electron, muon, or tau) can later be measured to have different flavor

$$c_{ij} = \cos\theta_{ij}, \;\; s_{ij} = \sin\theta_{ij}$$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\mathrm{CP}}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\mathrm{CP}}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Atmospherics / Accelerators — Reactors / accelerator s — Solar / reactors



- Indicate massive neutrinos
- Mix flavor and mass eigenstates

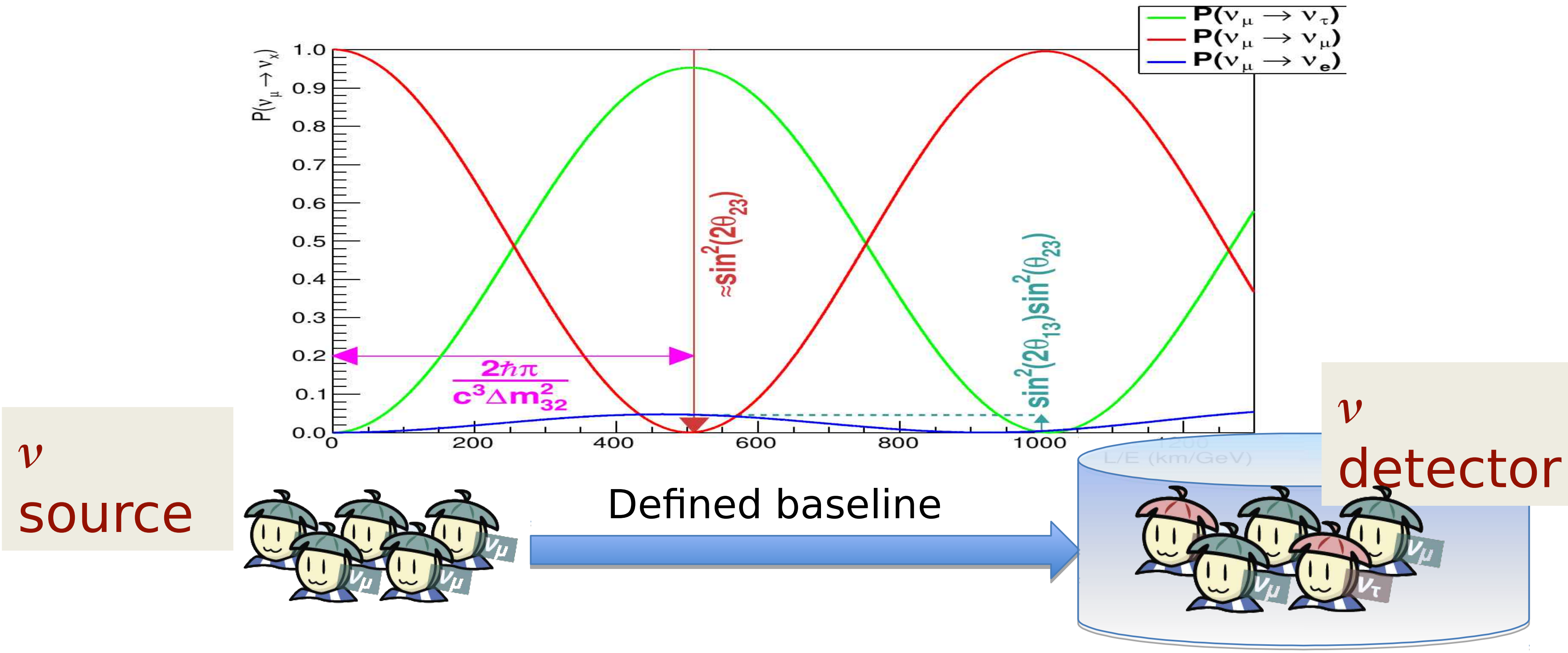
mass eigenstate: state of definite mass;

flavor eigenstate: state of definite flavor

- Beyond Standard Model

Neutrino Oscillation

$$P_{\mu\to x} \approx 1-\left(\cos^4\theta_{13}\cdot\sin^2 2\theta_{23}+\sin^2\theta_{23}\cdot\sin^2 2\theta_{13}\right)\sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$



Neutrino oscillation landscape

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\mathrm{CP}}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\mathrm{CP}}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Global fit – Normal hierarchy

$\Delta m^2_{21} = 7.50^{+0.19}_{-0.17} \times 10^{-5}\mathrm{eV}^2$

$\Delta m^2_{31} = 2.457^{+0.047}_{-0.047} \times 10^{-3}\mathrm{eV}^2$

$\theta_{12} = 33.48^{+0.78}_{-0.75}(^\circ)$

$\theta_{23} = 42.3^{+3.0}_{-1.6}(^\circ)$

$\theta_{13} = 8.50^{+0.20}_{-0.21}(^\circ)$

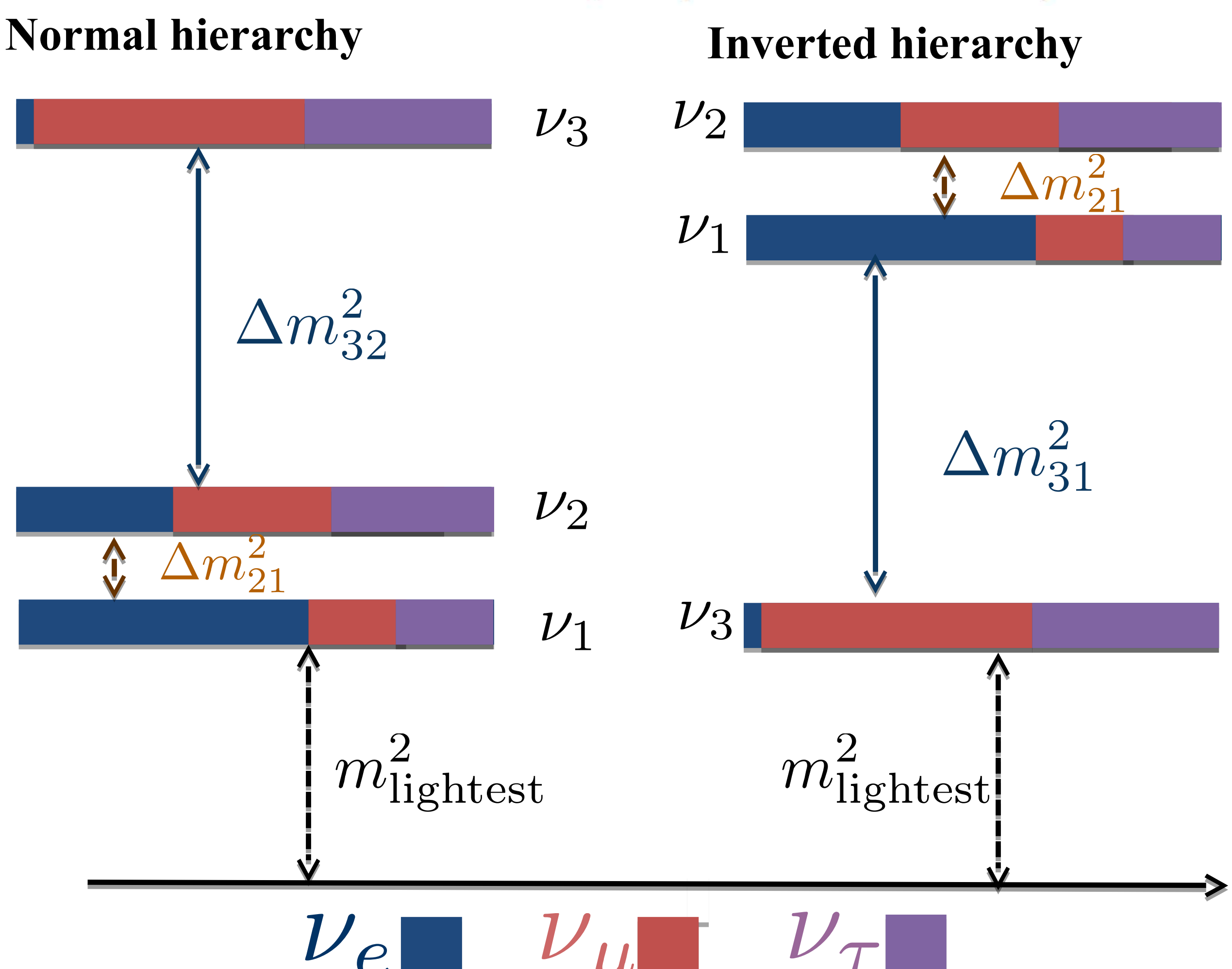
$\mathrm{sign}(\Delta m^2_{32}) =$?

θ_{23} is maximal ?

$\delta_{\mathrm{CP}} =$?

$m_{\mathrm{lightest}} =$?

Gonzalez-Garcia *et al.*, arXiv:1512.06856



$$\Delta m^2_{ij} = m^2_{\nu_i} - m^2_{\nu_j}$$

Issues of Neutrino

- Is the CP-violating phase δ non-zero, and if so, what is its value?

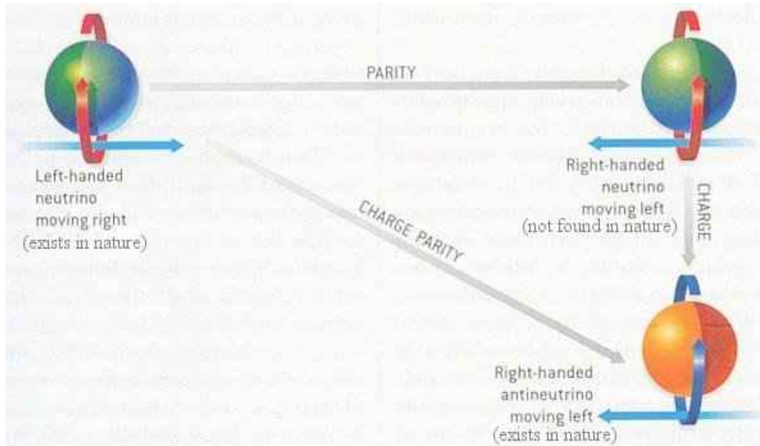
- Is the neutrino mass hierarchy “normal” (mass state 1, dominated by the electron neutrino, is the lightest) or “inverted” (mass state 3 is lighter than mass state 1)?

- Are there any sterile neutrino states, and if so, how many, and how do their masses compare to those of the “active”, Standard Model, states?

- What is the absolute neutrino mass scale?

CP Violation

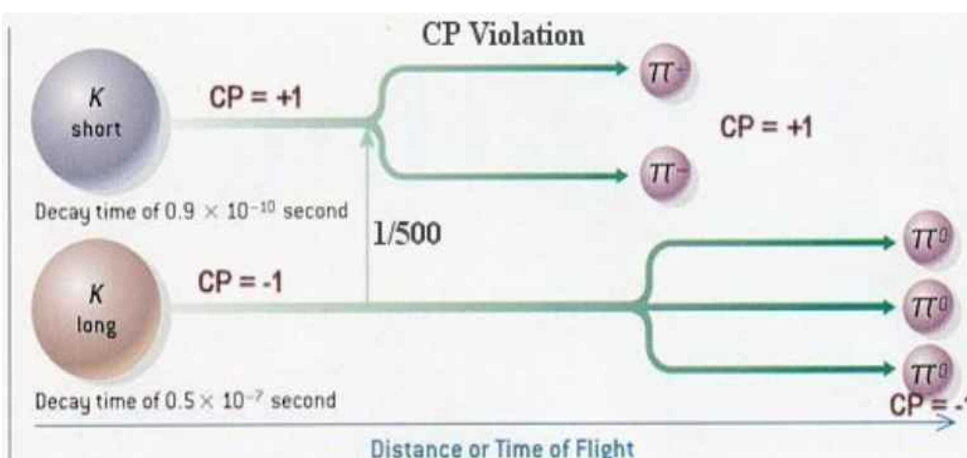
CP symmetry

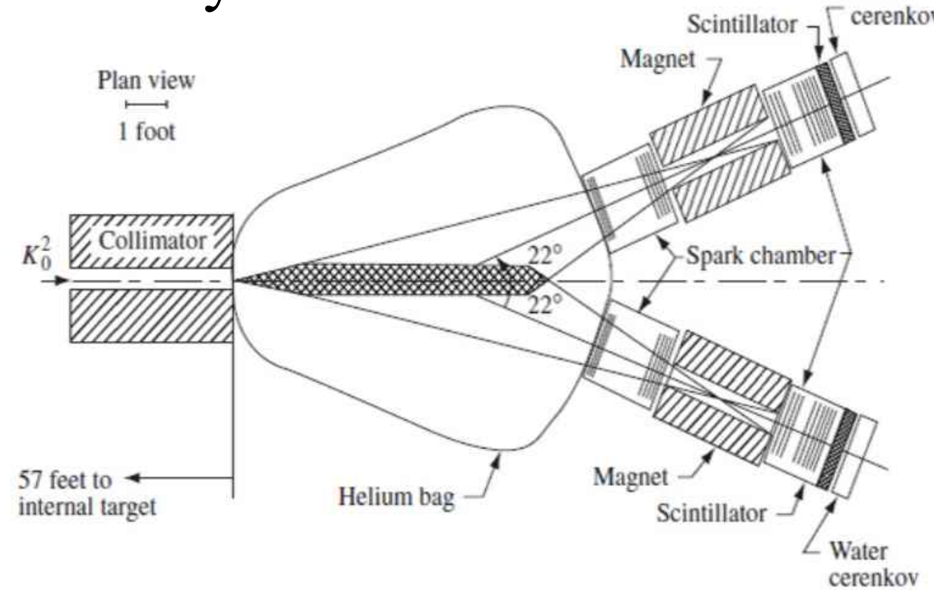


CP violation: a violation of CP transformed combination

(C - charged symmetry, P - parity symmetry)

1964: first discovery of CP violation in the decay of neutral kaons





CP Violation & Neutrino

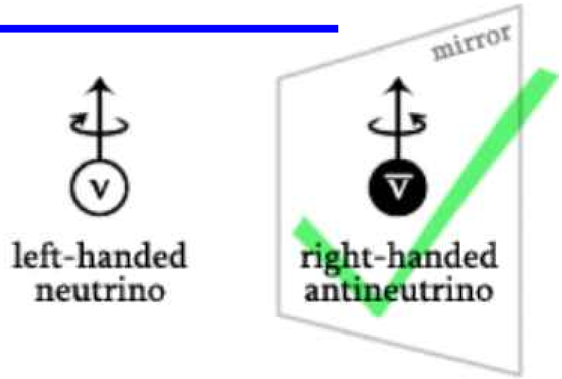
The matter-antimatter asymmetry problem is one of the unsolved problems.

- Hypothesis explains: come from the violation of the CP symmetry on neutrinos

- CP Violation has already been observed in quark oscillations and incorporated into quark mixing theory

→ more CP violation must be observed in order to explain the universe's matter dominance

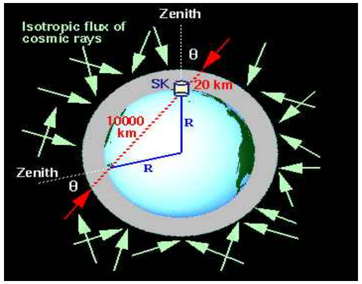
- neutrino in the CP symmetry

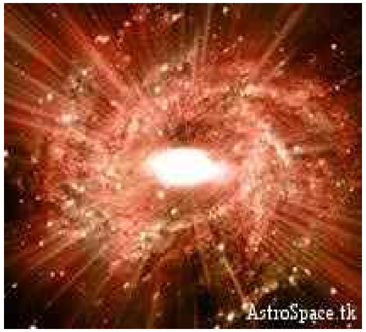


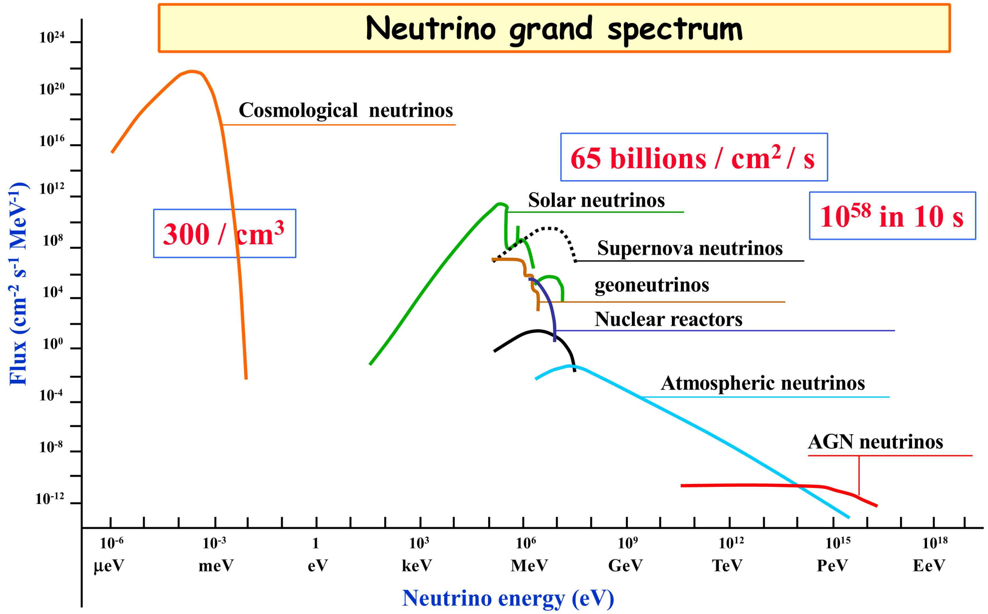
- If CP violation occurs in neutrinos, it will manifest itself as a difference in the oscillation probabilities of neutrinos and antineutrinos

$$P(\nu_\mu \rightarrow \nu_e) \neq P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$$

Neutrino sources





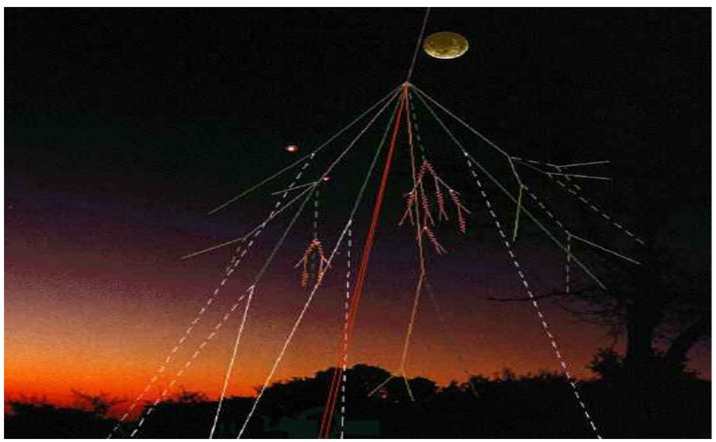


By F. Vannucci

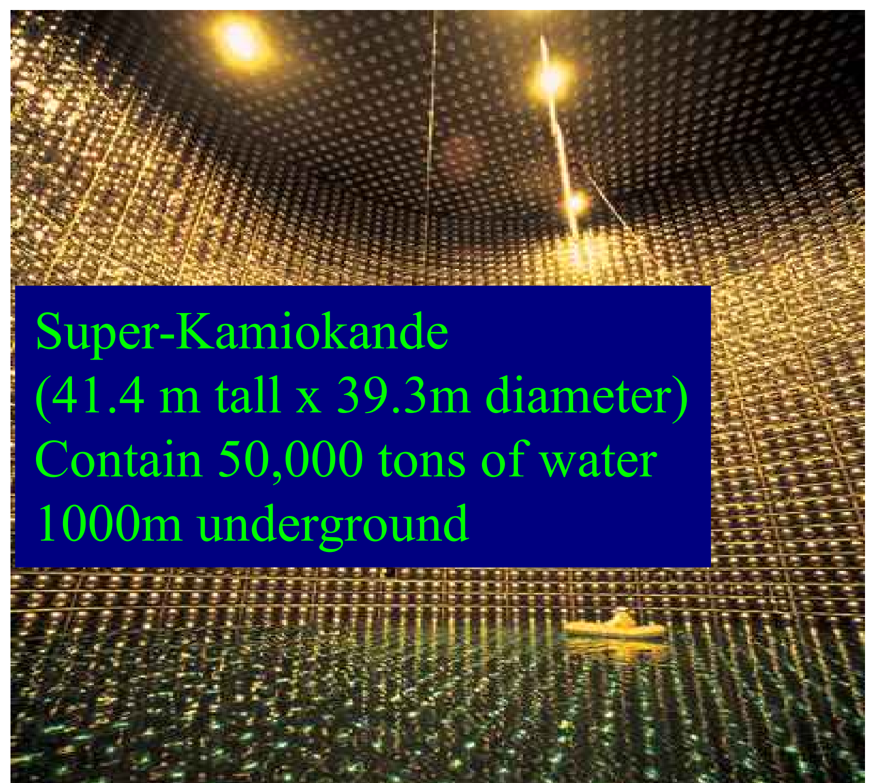
How To Detect Neutrino

- Neutrino interaction is very weak
→ need very big detector and/or powerful neutrino beam to study

100 events interactions, in 1 tons of water → need ~ 5x 10^{10} neutrino



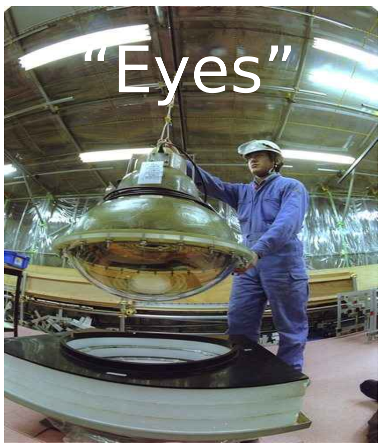
Also need to put underground to reduce the noise

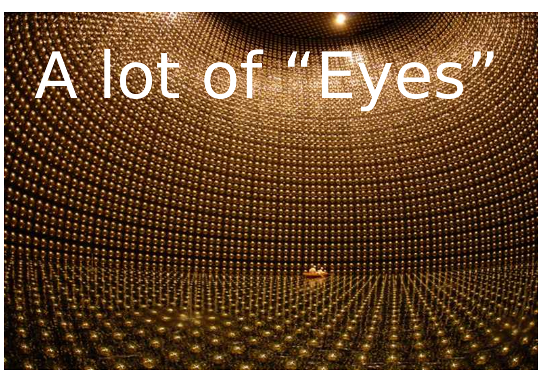


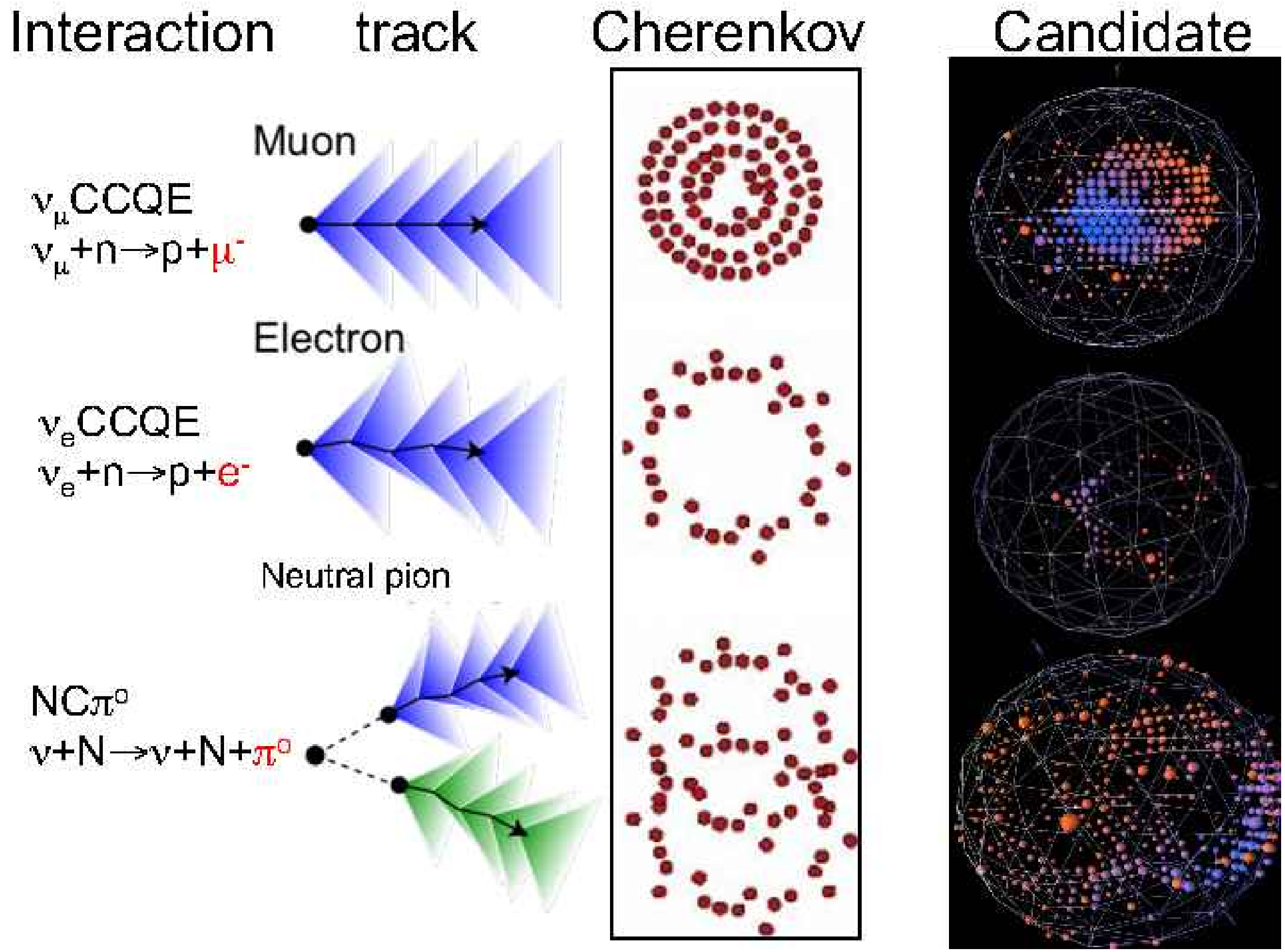
How To Detect Neutrino

Can't directly detect/see neutrinos.

→ Look at their trace when they interact w/ nuclear instead

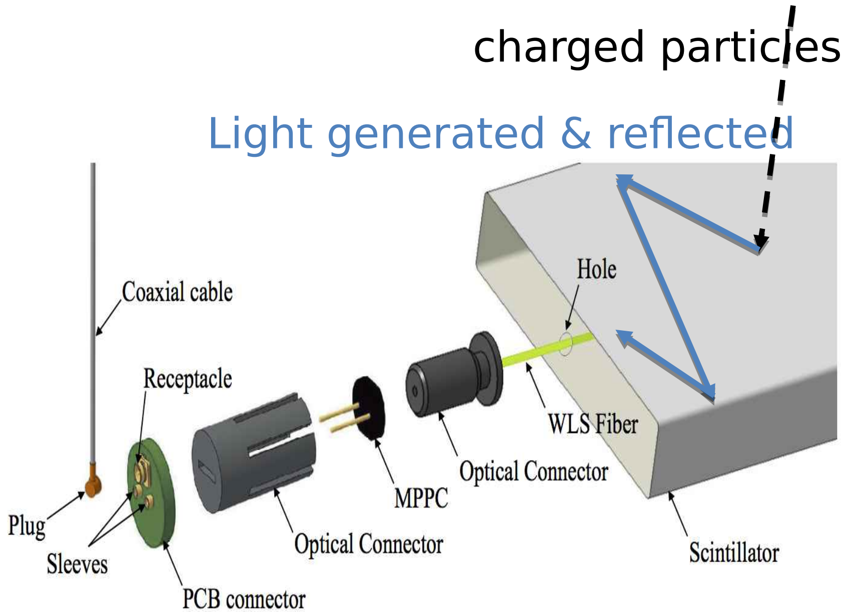


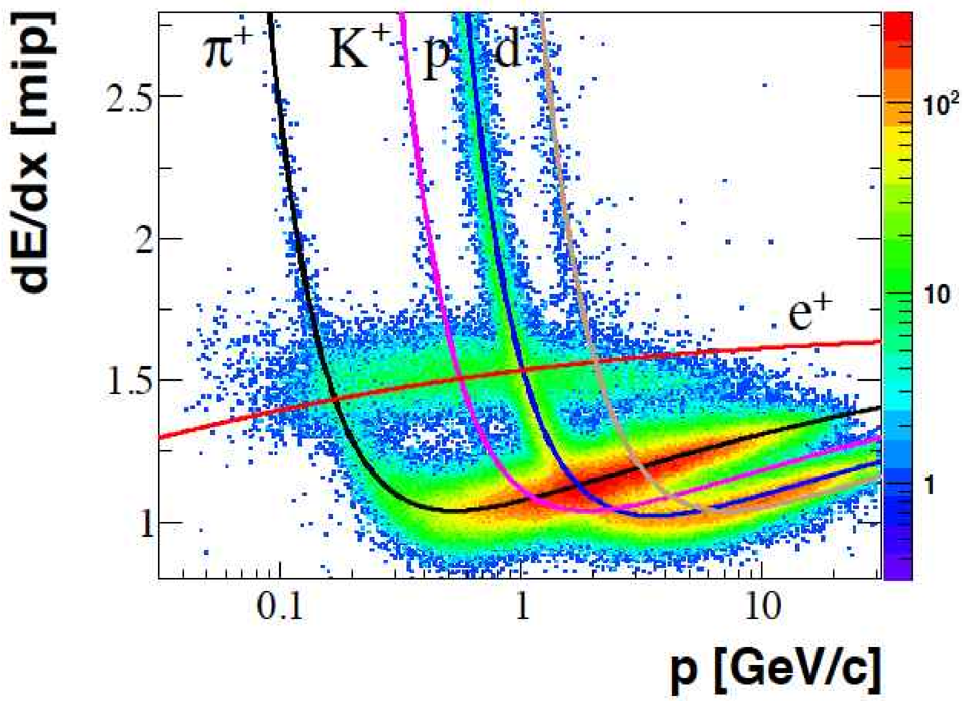




How To Detect Neutrino

Or use ionization to track charged particle by their stoping power





T2K Experiment

http://t2k-experiment.org/

- leading the search for CP violation in neutrino sector

- the discovery of $\nu_\mu \rightarrow \nu_e$ (i.e. the confirmation that $\theta_{13} > 0$)

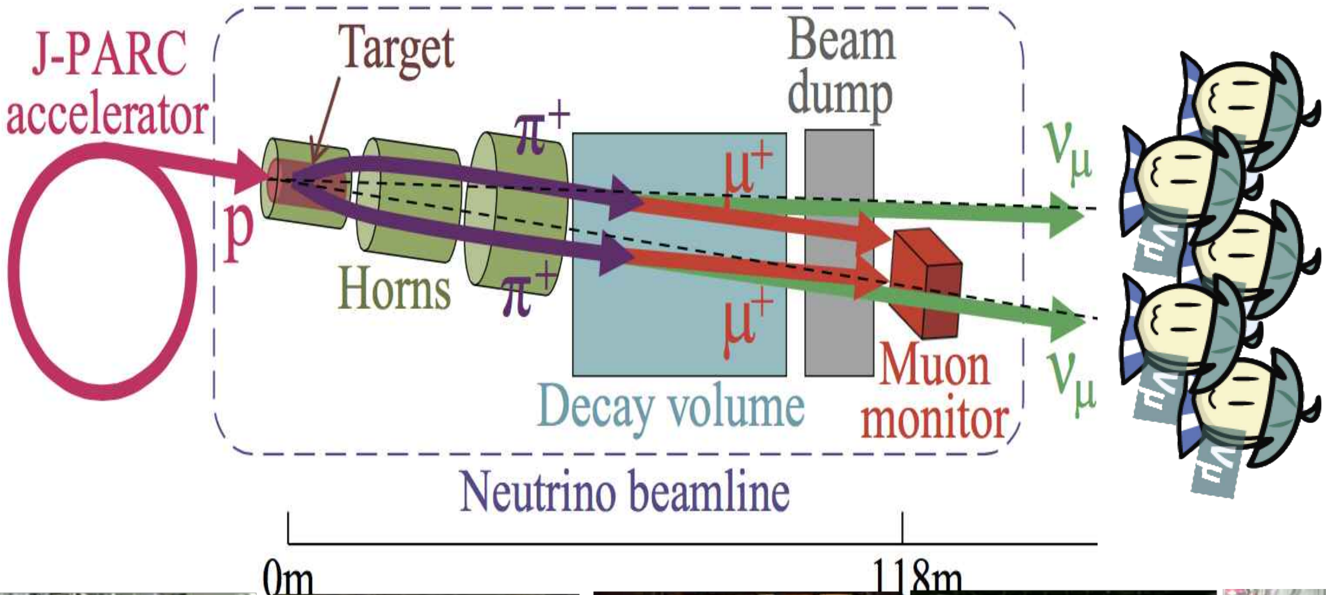
- precision measurements of oscillation parameters in ν_μ disappearance

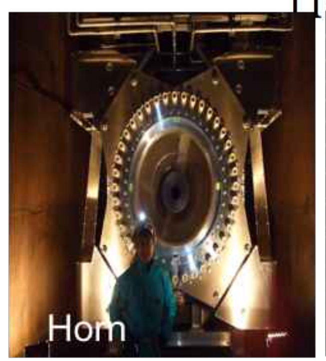
- a search for sterile components in ν_μ disappearance by observation of neutral-current events

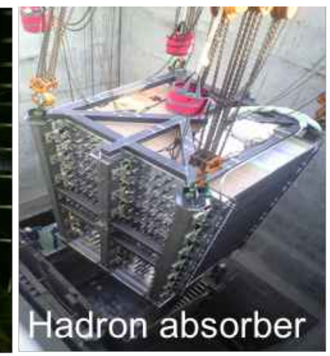
- search for $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$; precision measurement for $\overline{\nu_\mu}$ disappearance

- world-leading contributions to neutrino-nucleus cross-section measurements

How to Produce Neutrino Beam

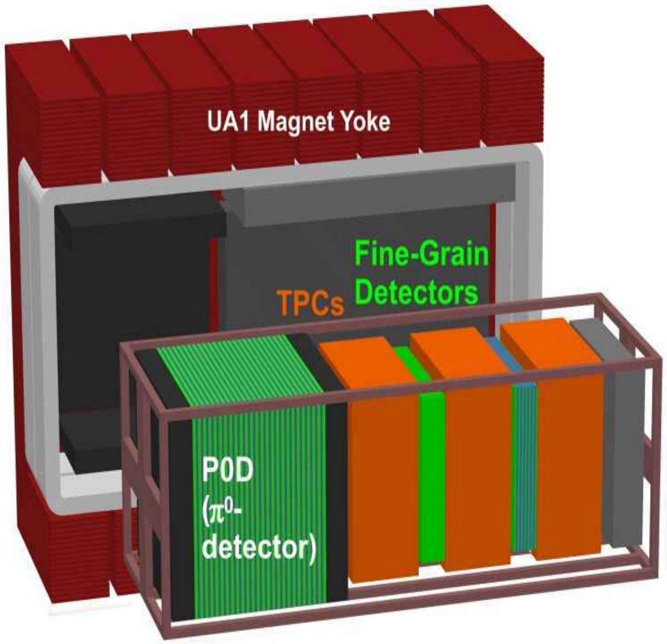




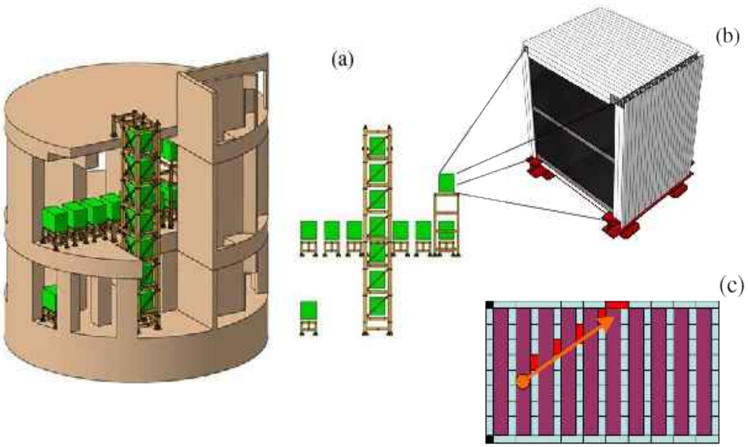


- 30 GeV pulsed proton beam
- Induced π^+ & π^- by three horns, pass through a 96-m decay pipe
- Beam dump to stop all particles except neutrinos and high-energy muons
- Muon monitor, downstream of beam dump, to monitor beam intensity and direction by measuring induced muon profile.

T2K Detectors



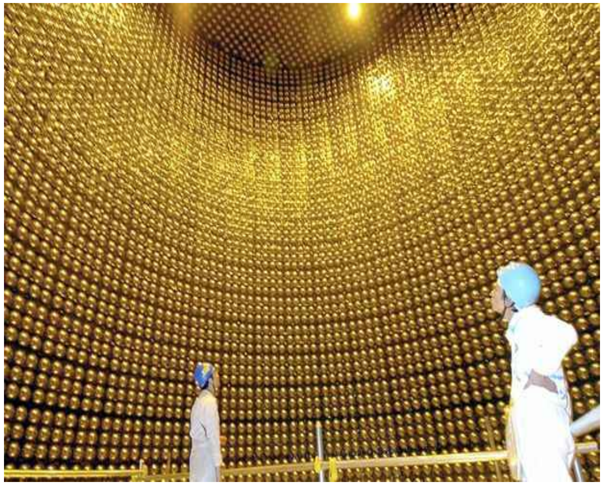
Near detector



◇ Off axis detector

◇ On axis detector

Far detector



OVERVIEW OF T2K EXPERIMENT

30 GeV proton beam

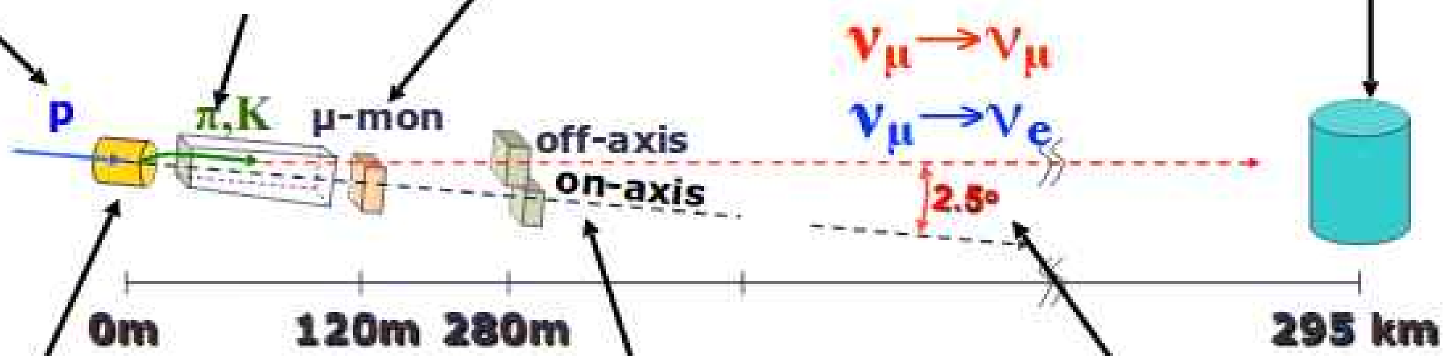
Decay volume:

$\pi^+ \to \mu^+ + \nu_\mu$

$\pi^- \to \mu^- + \bar{\nu}_\mu$

MUMON measures muons from pion decay

Off-axis **far detector** at 295 km: SK Cherenkov detector measures event rates after oscillations



Off-axis = narrow band beam

Beam on graphite target

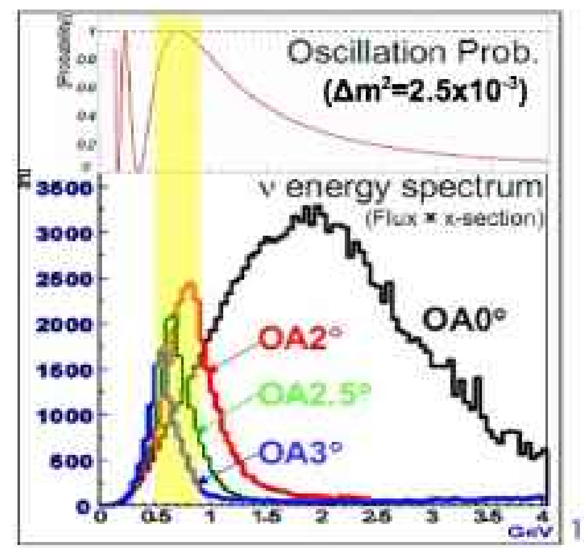
3 magnetic horns focus:

π^+ for neutrino mode

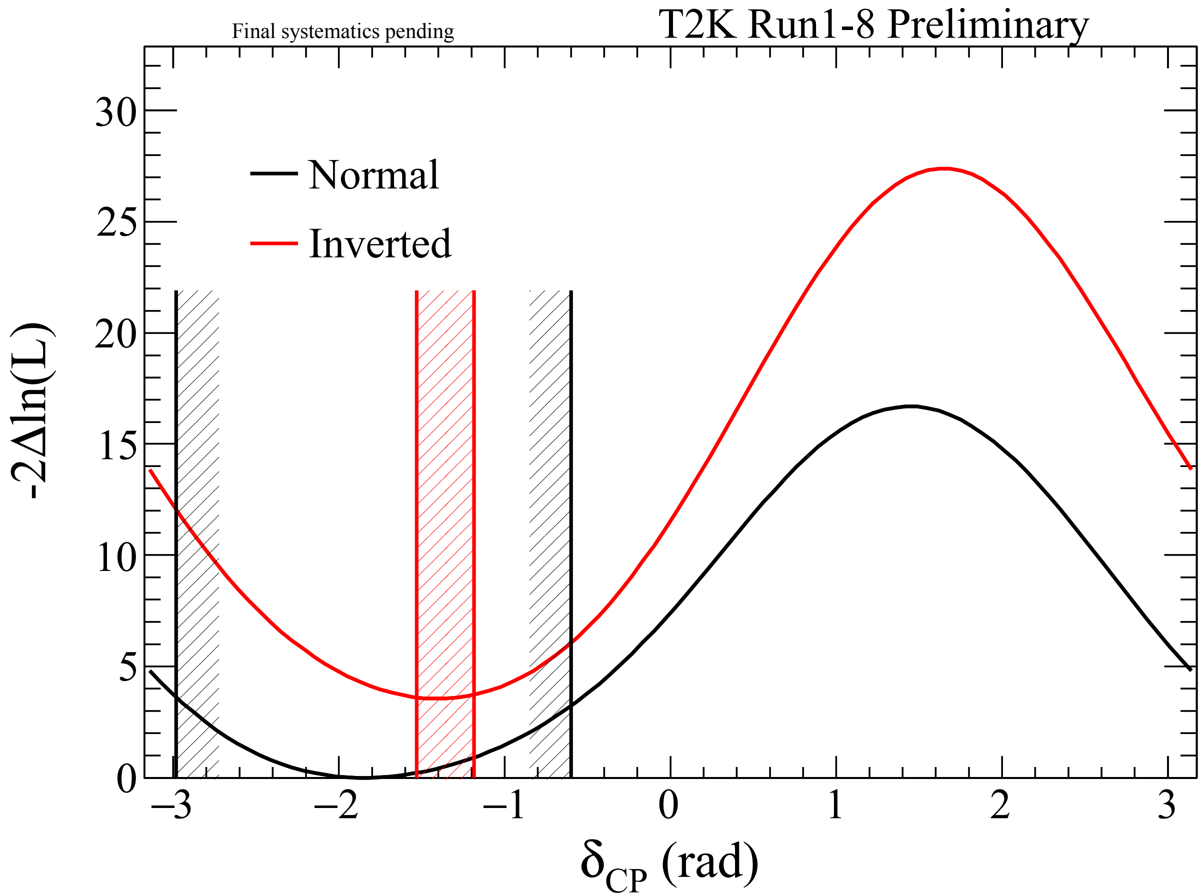
π^- for antineutrino mode

Off-axis **near detector**:
ND280 detector measures spectra interactions

INGRID on-axis detector monitors beam direction and neutrino rate



Results: δ_{CP}



T2K data: $\delta_{CP} = 0$ is excluded at 2σ CL.

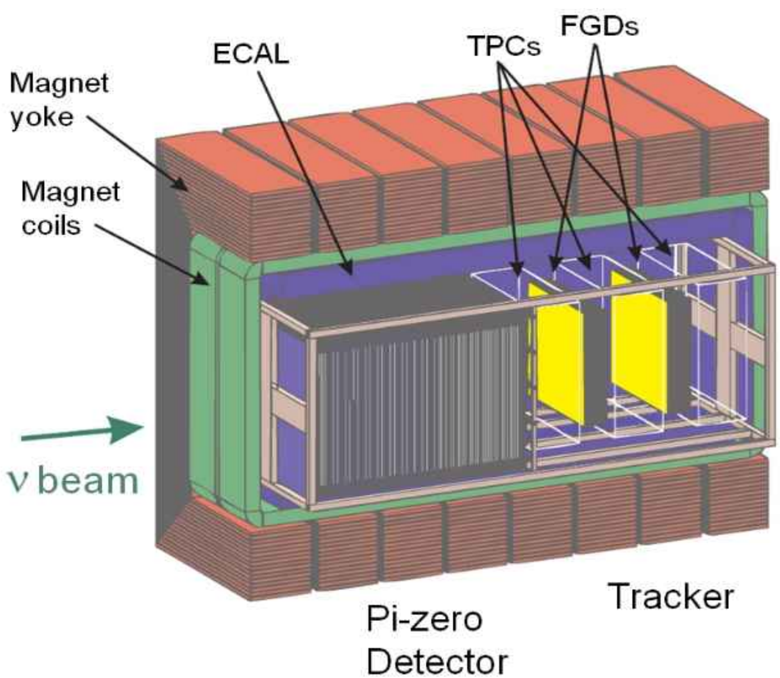
T2K is accumulating more data

For other result please visist   http://t2k-experiment.org/results/

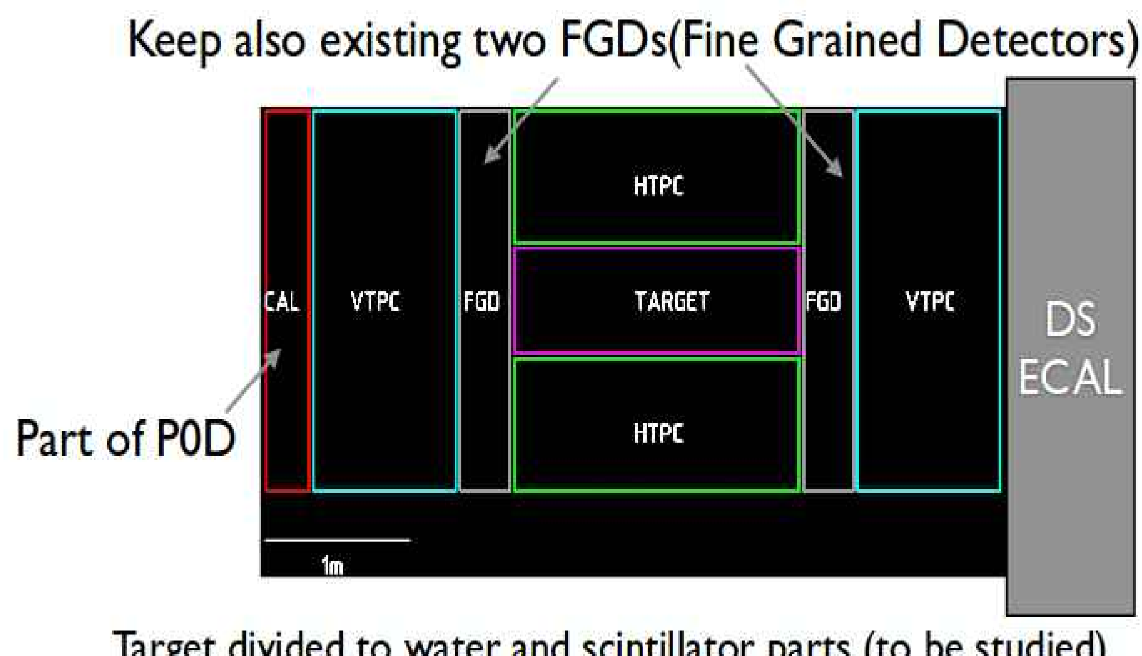
T2K-II and ND280 Upgrade

○ Aim for 3σ CP violation sensitivity by 2026
by accumulating 2×10^{22} POT with upgraded J-PARC (1.3MW)
○ Goal of systematics: reduce to 4% uncertainty on the event number predicted at Far Detection
→ Near Detector measurement is a key!
○ Upgrade of Near Detector (ND280) is under discussion inside T2K
~2020

Current design



Alternative design



ND280 Upgrade tentative schedule

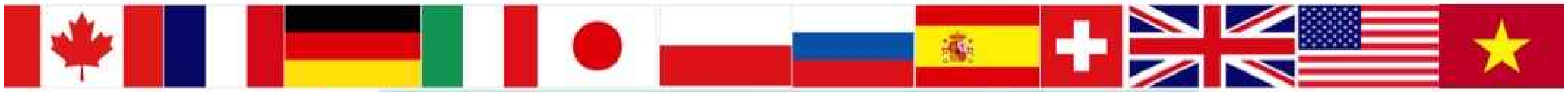
Schedule

○ 2017: detailed design of the detectors/setting up the project and the funding, proposal to SPSC
○ 2018-2019: construction of new detectors, possible beam test
○ 2020: shipment, installation, and commissioning

can we contribute for this activity
& also CP violation search with T2K?

Vietnam is now member of T2K – VN-neutrino group

The T2K Collaboration



~500 members, 64 Institutes, 12 countries

Canada
TRIUMF
U. B. Columbia
U. Regina
U. Toronto
U. Victoria
U. Winnipeg
York U.

France
CEA Saclay
LLR E. Poly.
LPNHE Paris

Germany
Aachen

Italy
INFN, U. Bari
INFN, U. Napoli
INFN, U. Padova
INFN, U. Roma

Japan
ICRR Kamioka
ICRR RCCN
Kavli IPMU
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Okayama U.
Osaka City U.
Tokyo Institute Tech
Tokyo Metropolitan U.
U. Tokyo
Tokyo U of Science
Yokohama National U.

Poland
IFJ PAN, Cracow
NCBJ, Warsaw
U. Silesia, Katowice
U. Warsaw
Warsaw U. T.
Wroclaw U.

Russia
INR

Spain
IFAE, Barcelona
IFIC, Valencia
U. Autonoma Madrid

Switzerland
ETH Zurich
U. Bern
U. Geneva

United Kingdom
Imperial C. London
Lancaster U.
Oxford U.
Queen Mary U. L.
Royal Holloway U.L.
STFC/Daresbury
STFC/RAL
U. Liverpool
U. Sheffield
U. Warwick

USA
Boston U.
Colorado S. U.
Duke U.
Louisiana State U.
Michigan S.U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

Vietnam
IFIRSE
IOP, VAST

Vietnam is now member of T2K – VN-neutrino group

On July 17th 2017, Neutrino Group at IFIRSE is officially formed with the MoU signing between Japanese Professors and Rencontres Du Vietnam at ICISE center.
More detail can be found at
http://ifirse.icise.vn/nugroup/OpenMoU.html

VN-neutrino group

- Leader: Tsuyoshi Nakaya (Kyoto Univ.)
- Member: Van Nguyen (IFIRSE & IOP)
- Affiliated member:
  - ○ Yuichi Oyama (IPNS, KEK);
  - ○ Atsumu Suzuki (Kobe Univ.);
  - ○ Trung Le (Tufts Univ.),
  - ○ Nhu Le (Hue Univ.)
  - ○ Makoto Miura (ICRR, Univ. of Tokyo);
  - ○ Son Cao (IPNS, KEK);
  - ○ Minh Truong (DUT)
  - ○ Le Thi Que (VNUHCM)
- Students:
  - ○ Tran Van Ngoc (Ph.D candiadate),
  - ○ Nguyen Thi Kim Ha (B4)

Need more student Master & Ph.D, more details at
http://ifirse.icise.vn/nugroup/Student-call-2017-vn.html

Also look for collaboration from Vietnam researchers

Previous neutrino school at http://ifirse.icise.vn/nugroup/vson/2017/

The 2nd school from July 8th - 21st 2018

VN-neutrino group

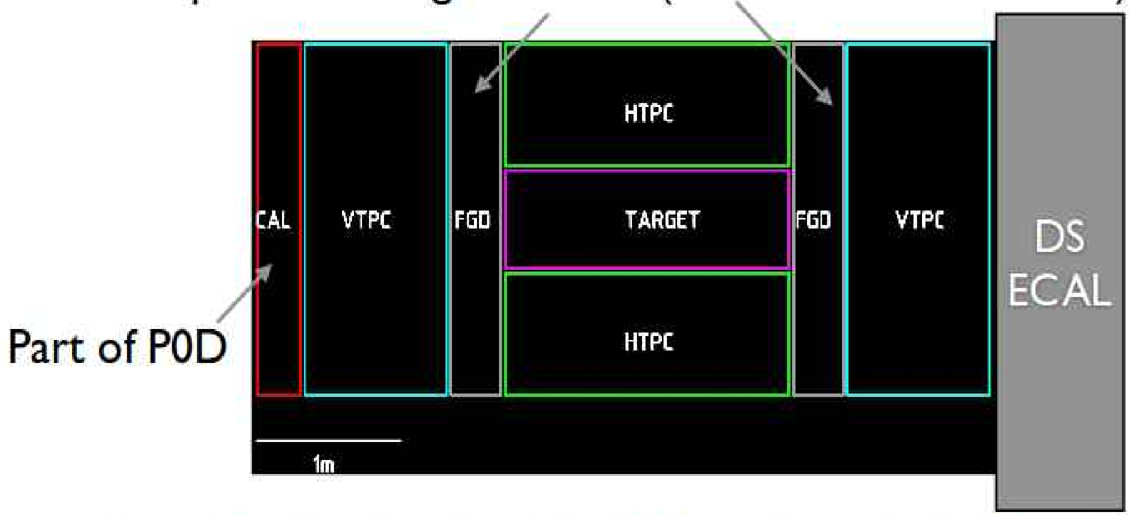
- What will we do ?
  - ○ T2K and test experiment at J-PARC
    - +Simulation with NEUT and implement the latest neutrino-nucleus interaction models
      → neutrino interaction mode
      (NEUT=Neutrino Event Generator)
    - +Neutrino beam measurement
      joint study of beam monitor measurement,
      MUMON measurement and INGRID measurement
    - +Measure neutrino interaction cross section with T2K near detector & J-PARC test experiment (WAGASCI, NINJA)
    - +Measure CP violation by combining T2K data and Super-K atmospheric data

VN-neutrino group

- What will we do ?
  - ○ Develop in VietNam
    - + MPPC study with 3rd generation
    - + MPPC array
    - + build detector prototype

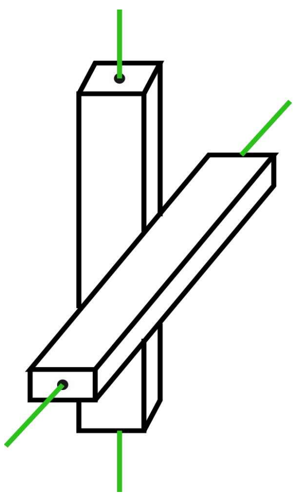
….

Keep also existing two FGDs(Fine Grained Detectors)



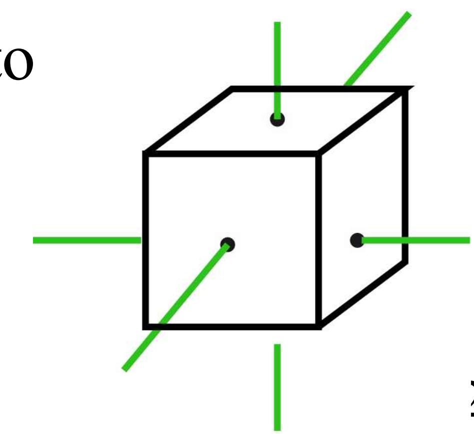
Target divided to water and scintillator parts (to be studied)

Scintillator bars



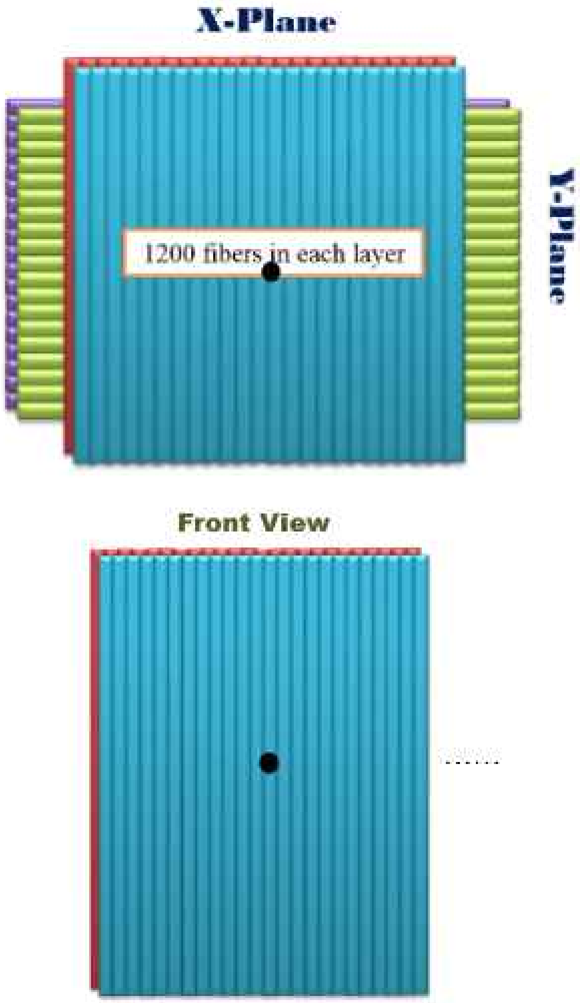
⇓

Scintillato cube



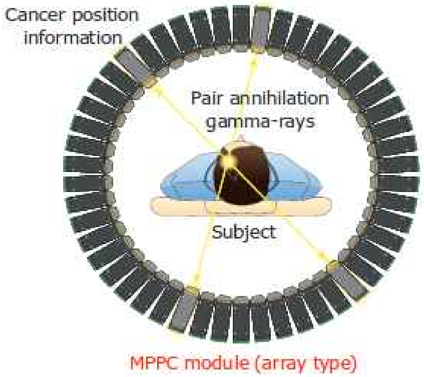
VN-neutrino group

- What will we do ?
  + MPPC array



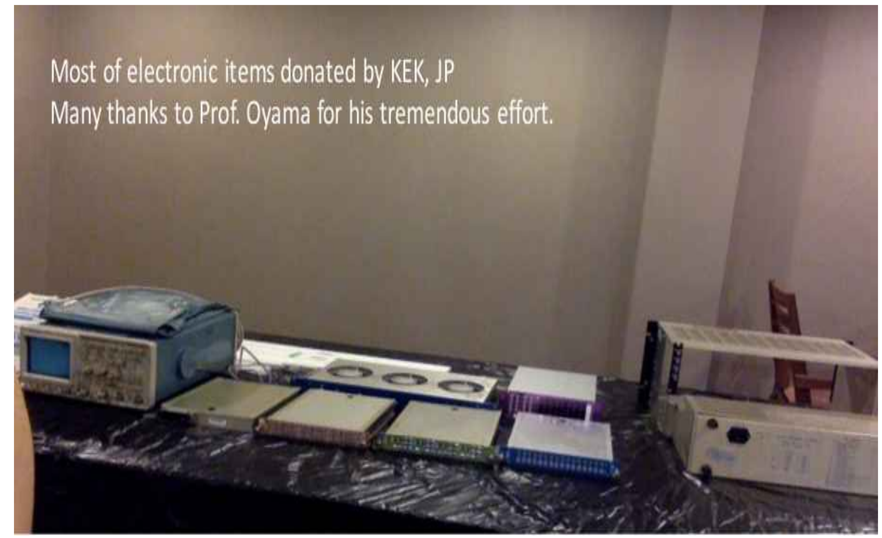
  + scintillator fiber tracking

  + PET



https://userweb.jlab.org/~yez/Work/SFT/SFT_Status.pdf

VN-neutrino group



Thanks for your attention

Contact us:
CVSon : cvson@post.kek.jp
NHVan : nhvan@iop.vast.ac.vn
NMTruong: nguyenminhtruong0101@gmail.com

Backup

Begin of Universe

1,000,000,0
01
Baryons

1,000,000,0
01
Anti-
Baryons

?

Shortly after

1,000,000,0
02
Baryons

1,000,000,0
00
Anti-
Baryons

(Fukugita, Yanagida)

(B ≠ 0; L ≠ 0)

$\Gamma\left(N \to \ell^- + H^+\right) \neq \Gamma\left(N \to \ell^+ + H^-\right)$

$N \to \ell^{\mp} + H^{\pm}$

$N \to \overset{(-)}{\nu} + \overset{(-)}{H^0}$

CP-violating decays
(B = 0; L ≠ 0)

+

Sphaler
on
Process

$\Gamma\left(N \to \nu + H^0\right) \neq \Gamma\left(N \to \overline{\nu} + \overline{H^0}\right)$

- Can it be due to CP-violating decays of heavy neutrinos?