

# How to convince people that neutrinos are interesting?



NATIONAL CENTRE  
FOR NUCLEAR RESEARCH  
ŚWIERK

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1 June 2026

# Give answer to basic questions

- What elementary particles are? Why they are interesting to us?
- What are neutrinos ?
- What do we know about them?
- How we explore neutrino physics? What we are doing in **Super-Kamiokande**, **T2K** and **Hyper-Kamiokande** in Japan?

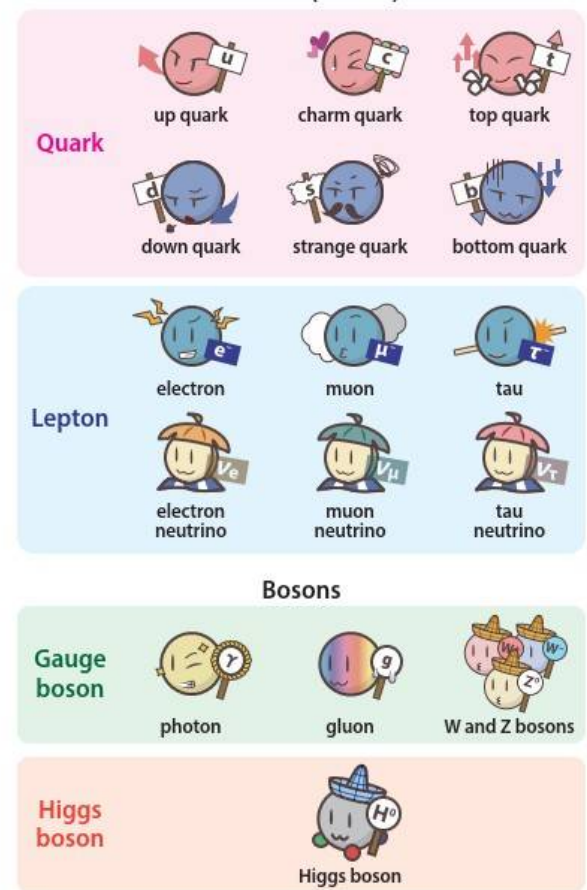
Hunting for neutrinos  
with Super-Kamiokande  
detector



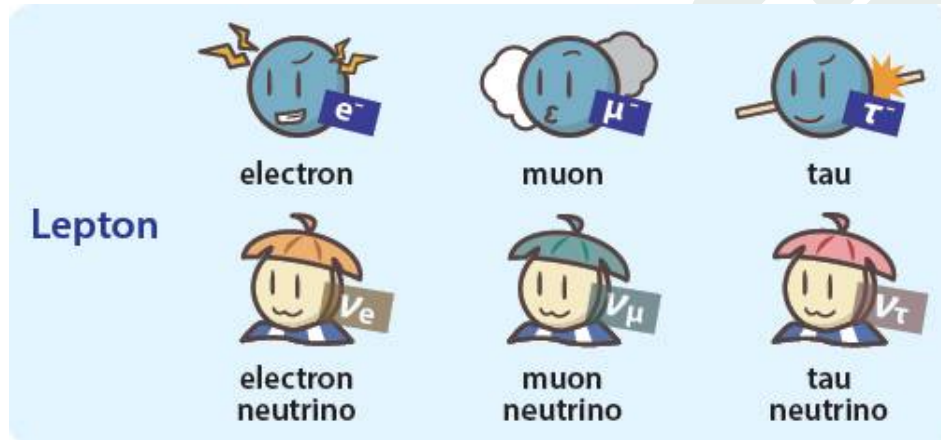
# Introducing neutrinos

Start from something what people should now from school: **molecules** → **atoms** → **protons, electrons** →

→ and go deeper into it ... **defining other elementary particles** and forces between them



# What the word "Neutrino" means?



"Neutral" – means zero electric charge  
"-ino" – means tiny from Italian

"Neutral" and "ino" → "Neutrino"

# Where can we find them?

## Atmospheric

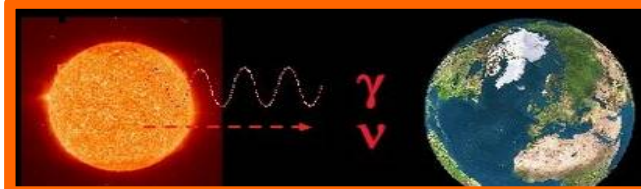


Sun emits:

$$2 \times 10^{38} \text{ v/s}$$

The Earth reaches

$$40 \times 10^9 \text{ v/s/cm}^2$$



## Solar

## Reactor



## From Supernovae

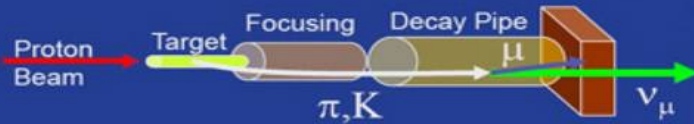


## from Big Bang



$$330 \text{ v/cm}^2$$

## Accelerator



# Some facts about neutrinos

- Neutrinos from the Big Bang are passing through the Universe



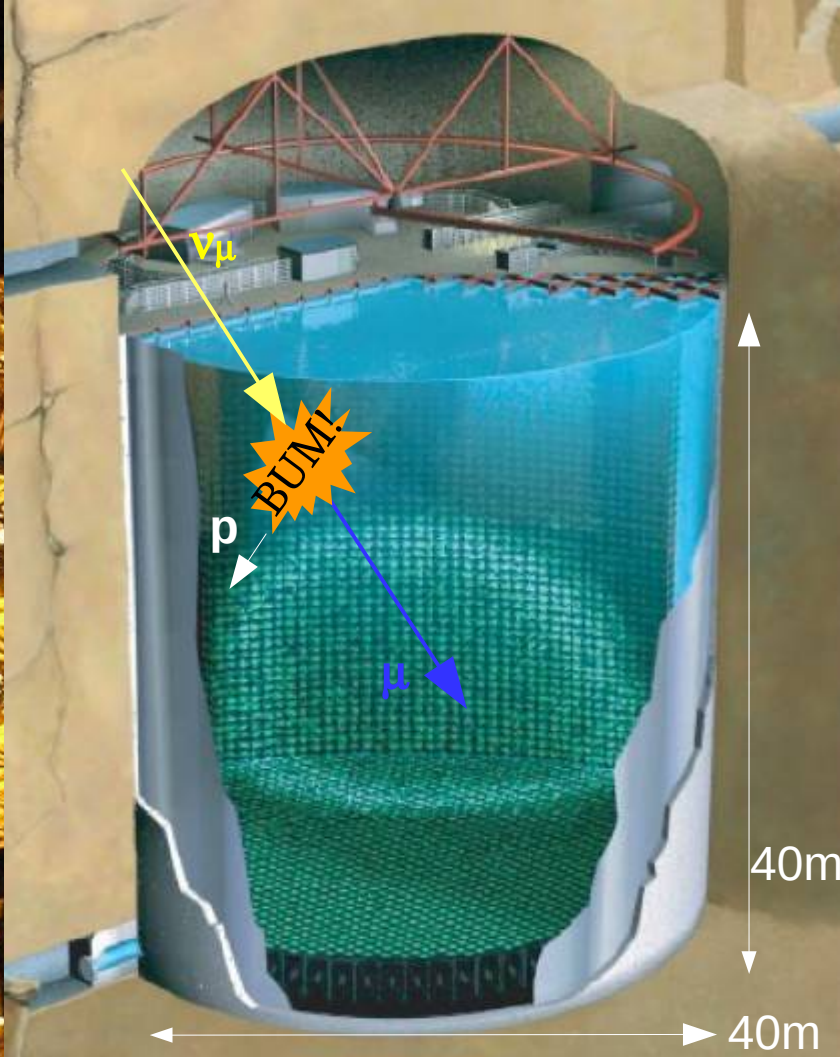
Through the person passes  
30 000 000 neutrinos  
From the Big Bang

- In order to **stop neutrino** one needs block made of lead which is **3 light years** thick, so 200 000 times more than distance from the Sun to the Earth
- We can find only 1 neutrino interaction in the body through the ones live

➔ **We need huge, massive detectors to measure neutrinos**

# Super-Kamiokande Detector

- Placed in Japanese Alps
- Placed 1km underground
- Filled with 50-kton of ultra-pure water
- Equipped with ~11000 20-inch Photomultiplier tubes



*Joanna Zalińska, NCBJ*



*Jan Kisiel, UŚ*



*Katarzyna Kowalik,  
NCBJ*



*Robert Kurjata,  
WUT*

*Marcela  
Batkiewicz, IFJ*

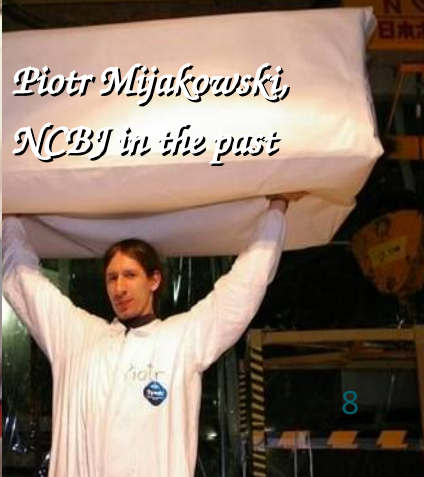


*Justyna Łagoda, NCBJ*

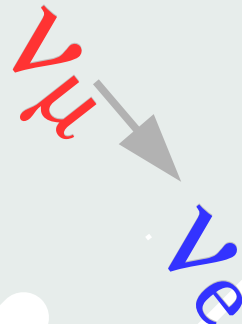
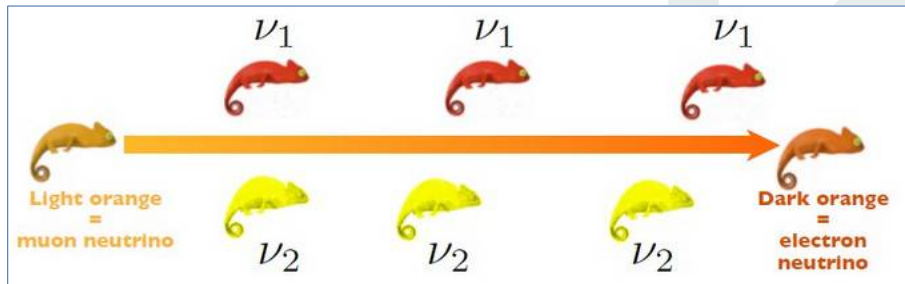
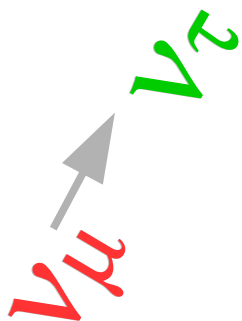


*Anna  
Dąbrowska, IFJ*

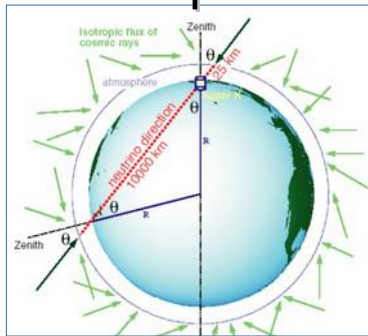
*Piotr Mijakowski,  
NCBJ in the past*



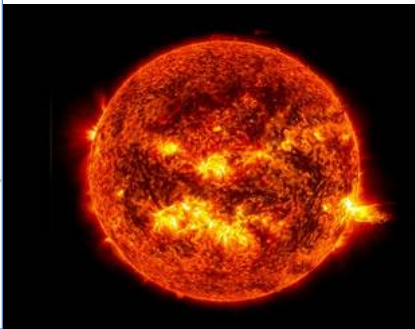
# Observation of neutrino oscillation



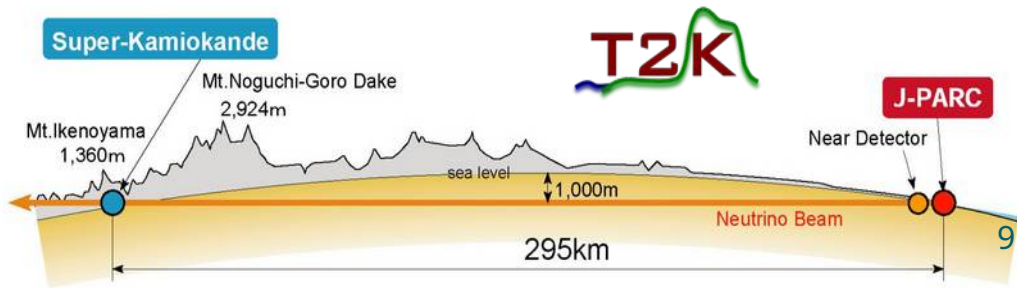
## Atmospheric



## Solar



## Accelerator neutrinos





# Recognition on the World

## Nobel Prize 2015

For discovery of neutrino oscillation, which shows that neutrinos have masses



**Takaaki Kajita**  
**Super-Kamiokande**



**Arthur McDonald**  
**SNO**

## Breakthrough Prize 2016

For the fundamental discovery and exploration of neutrino oscillations



Y. Wang and Kam-Biu Luk (Daya Bay); A. Suzuki (KamLAND); **K. Nishikawa (K2K / T2K)**; A. McDonald (SNO); and **T. Kajita and Y. Suzuki (Super-Kamiokande)**



# Nobel Prizes in Neutrino Physics

- **1988: L. Lederman, M. Schwartz, J. Steiberger**

for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino

- **1995: F. Reines**

for the detection of the neutrino

- **2002: R. Davis, M. Koshiba**

for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos

- **2015: T. Kajita, A. McDonald**

for discovery of neutrino oscillations, which shows that neutrinos have masses



# Neutrino experiments

Super-Kamiokande

SNO

T2K

NovA

OPERA

ICARUS

MINOS

K2K

Borexino

Antares, KM3Net

IceCube

DayaBay

RENO

Double-CHOOZ

Minerva

MicroBoone

GERDA

Kamland-ZEN

Kamland

Kamiokande

SNO+

EXO

NEMO

CUORE

KATRIN

JUNO

Hyper-Kamiokande

DUNE

INO

Savannah River

Homestake

Gallex

IMB

DONuT

....



# What's unknown?

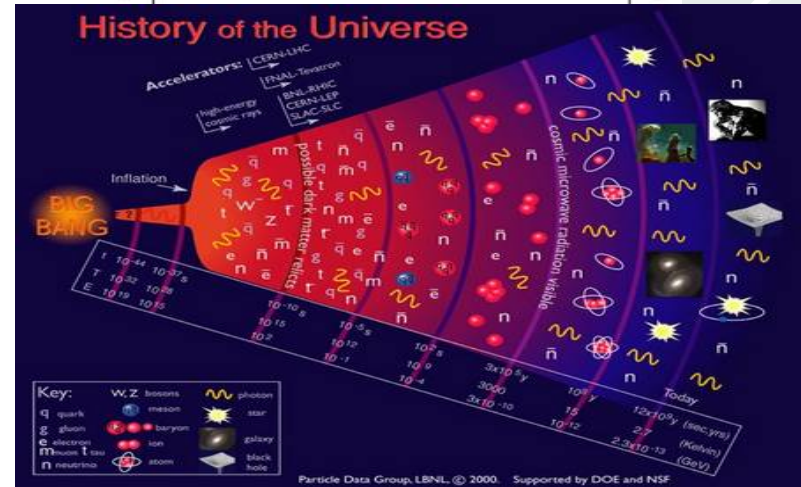
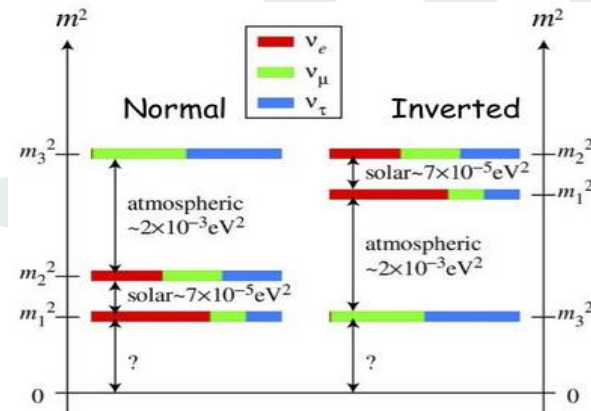
- It was proved that **neutrinos have masses**, but we do not know **what mass of neutrino is?** We are **measuring  $\Delta m^2$**  through oscillations, but **which hierarchy exists?**



Is **CP conserved or violated** in neutrino oscillations?

- Neutrinos from the Big Bang** are so abundant ... but have very low energy ... nobody has figured out yet **how to detect them.**

## Neutrino mass hierarchies



Relict neutrinos  
Predicted energy  $10^{-4} - 10^{-6} \text{ eV}$

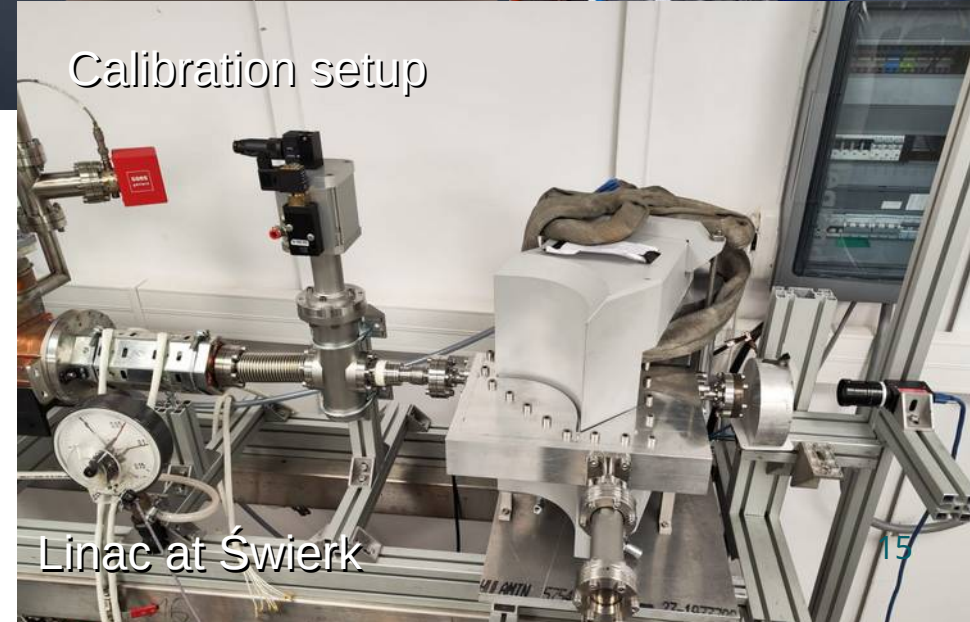
# Building Hyper-Kamiokande

- Measurement of neutrino oscillations from the JPARC neutrino beam  $\nu/\bar{\nu}$ 
  - Search for CP violation
- Which mass hierarchy?
- Search for proton decay
- Atmospheric neutrinos
- Astrophysics:
  - solar neutrinos
  - supernovae neutrinos
  - dark matter search



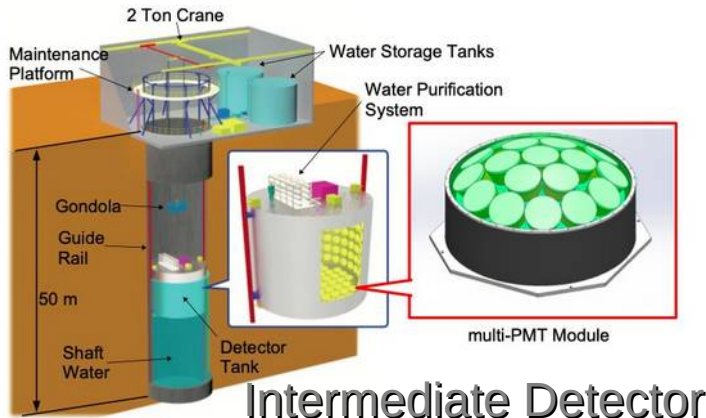
# Polish contribution to Hyper-K

- **NCBJ is building linac for Hyper-K**  
Particle Accelerators Physics & Technology Division (TJ1)
  - low energy electrons 3-24 MeV
  - low intensity – single electrons needed
  - electron injection system to the tank
- Will be **use for calibration of energy**
  - one of the most difficult and important detector tuning
- Build and tested at NCBJ-Świerk, will be shipped to Japan



# Polish contribution to Hyper-K

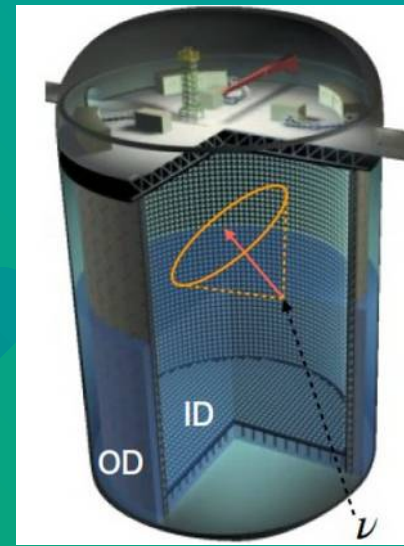
- **WUT was assembling multiPMTs**
- **WUT is designing electronics for mPMTs**
- mPMTs were used in **test experiment at CERN**
- mPMTs will be used also in **Hyper-K Detector** for calibration and the **Intermediate Detector** will be equipped with mPMTs only



# Neutrino physics provides basic understanding of the Standard Model and the Universe



A lot of have already been measured



We are in excited time of building new experiment



**STAY TUNED !!!**

