

# Introverts among elementary particles - neutrinos

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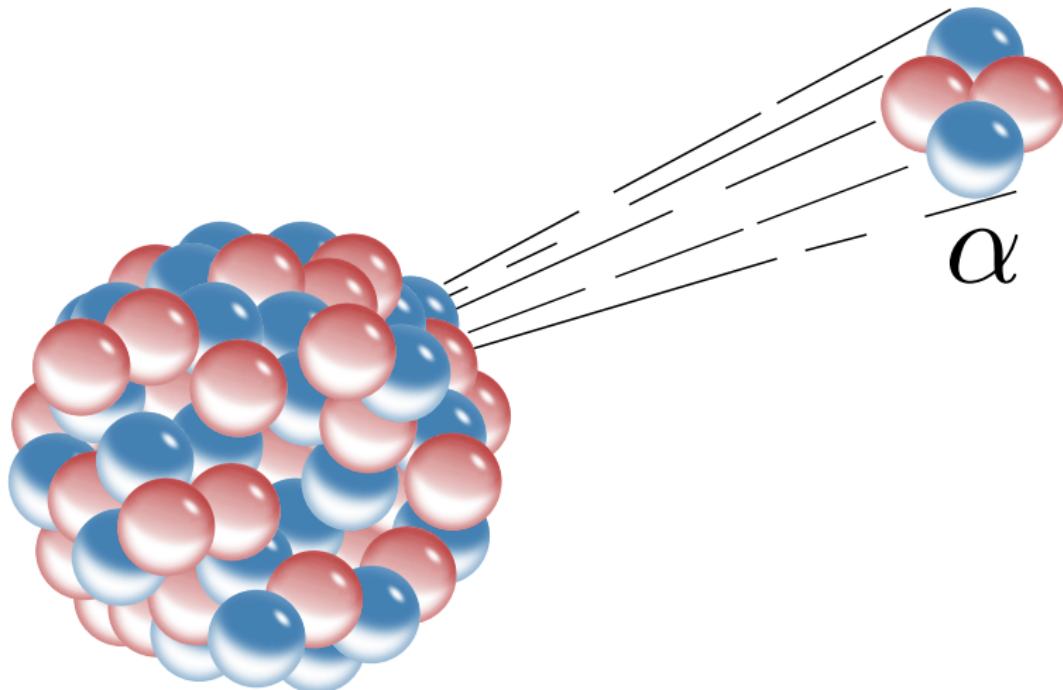
## Learning objectives

- Describe what is a neutrino
- Characterize the features of a good neutrino detector
- Solve the Solar neutrino problem

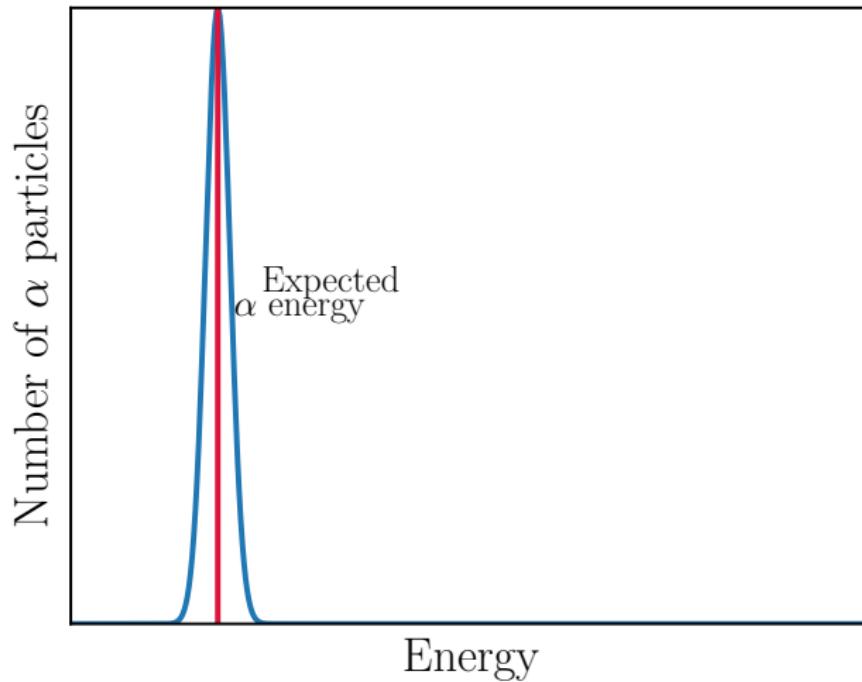
# **Data interpretation 101 by W. Pauli**

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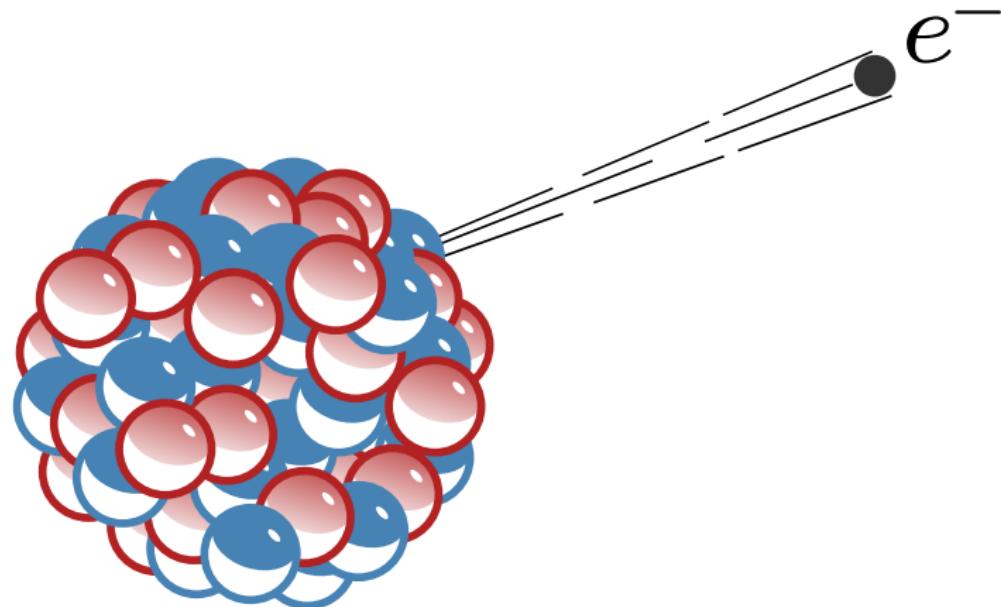
## Alpha decay



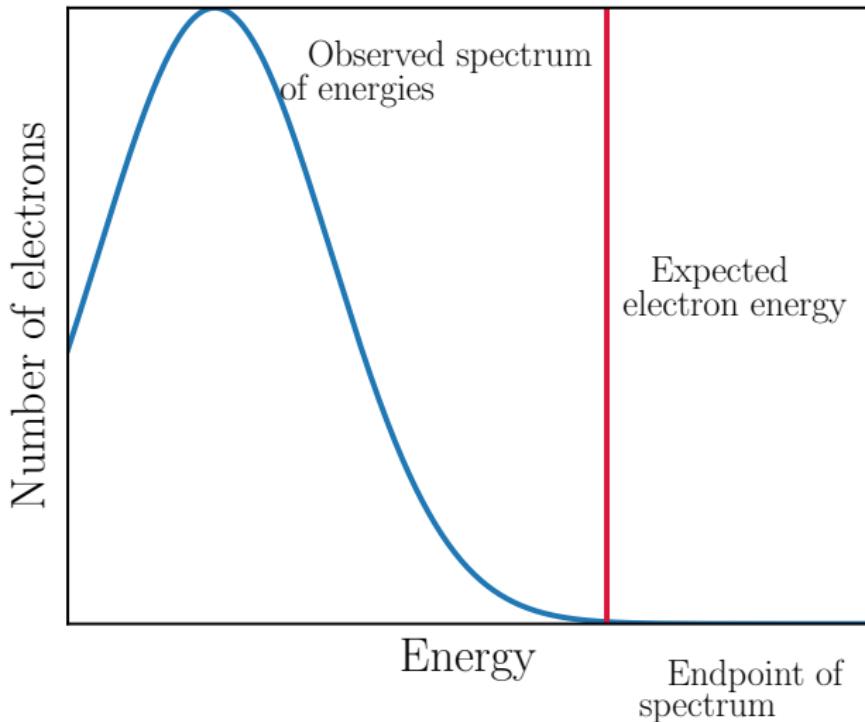
# Alpha decay



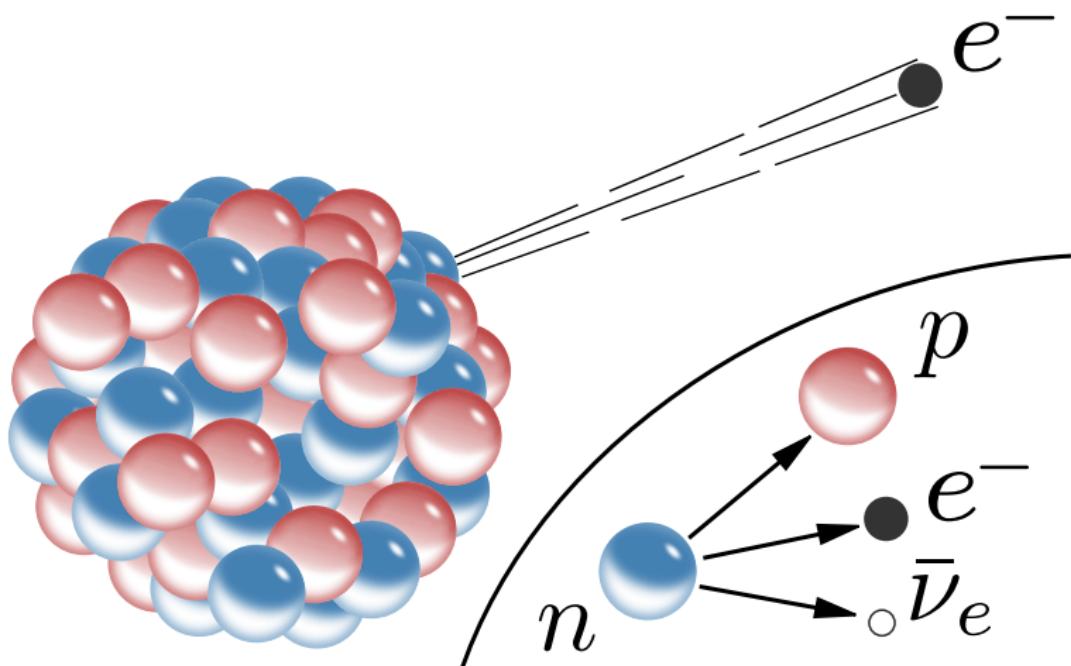
## Beta decay



# Beta decay



## Beta decay



# Neutrinos

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# Neutrino flavors



# Neutrino flavors



# Neutrino flavors



# Neutrino flavors



# Neutrino flavors



# Neutrino flavors



## How to catch a ghost?

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# Neutrino reactors



Kurzgesagt, Wikipedia

# Neutrino reactors



Kurzgesagt, Wikipedia

# Neutrino reactors



Kurzgesagt, Wikipedia

# Homestake experiment - neutrino detector



# Homestake experiment - neutrino detector



① BIG detector

# Homestake experiment - neutrino detector



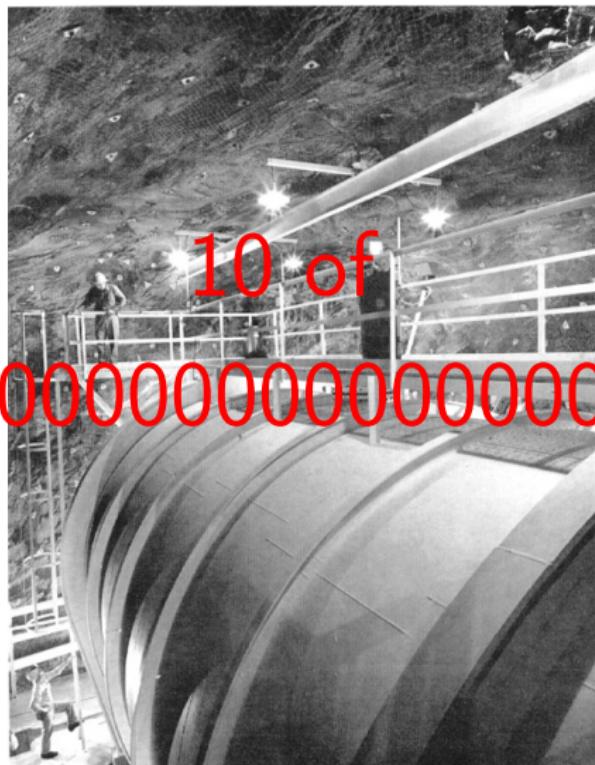
- ① BIG detector
- ② isolate from other crap

# Homestake experiment - neutrino detector



- ① BIG detector
- ② isolate from other crap
  - 380 m<sup>3</sup> of perchloroethylene  
(dry-cleaning fluid)
  - 1.5 km underground

# Homestake experiment - neutrino detector



- ① BIG detector
- ② isolate from other crap
- 380 m<sup>3</sup> of perchloroethylene  
(dry-cleaning fluid)
- 1.5 km underground

# Twist



  $v_e$      $v_\mu$      $v_\tau$

mass states  $\neq$   
flavor states



# Problem

Why scientist measured only 3 neutrinos if they calculated that the expected number is 10?



The Infamous "Neutrino-burglar"

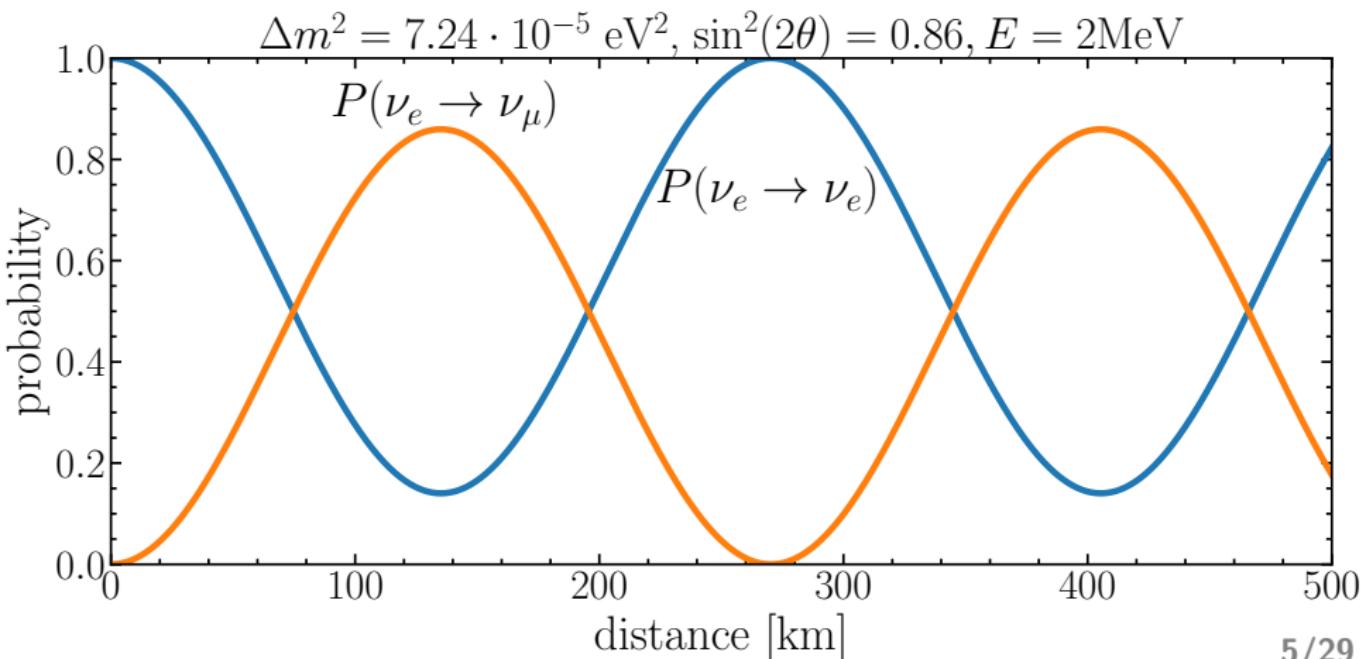
<https://astrodidyouknow.blogspot.com/2011/>

# Neutrino oscillations in vacuum

$2\nu$  mixing = easy dependence on

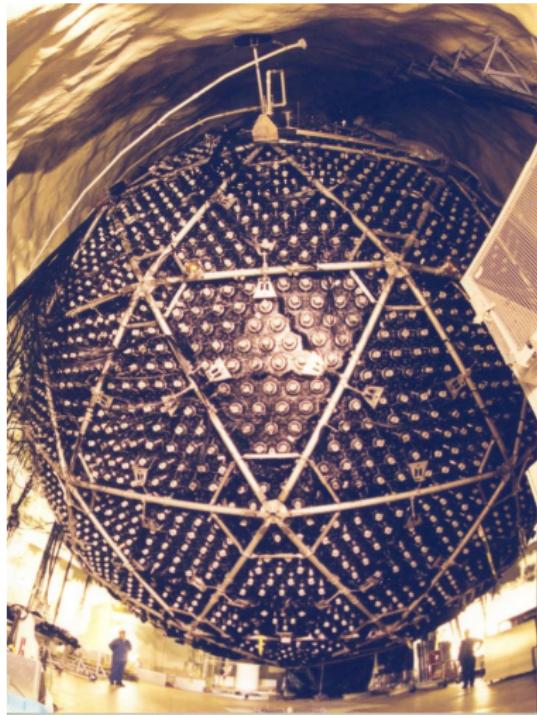
$$P_{\nu_e \rightarrow \nu_e} = 1 - \sin^2 2\theta \sin^2 \frac{\Delta m^2 L}{4E}$$

- mixing angle
- mass squared difference



# Hungry detector

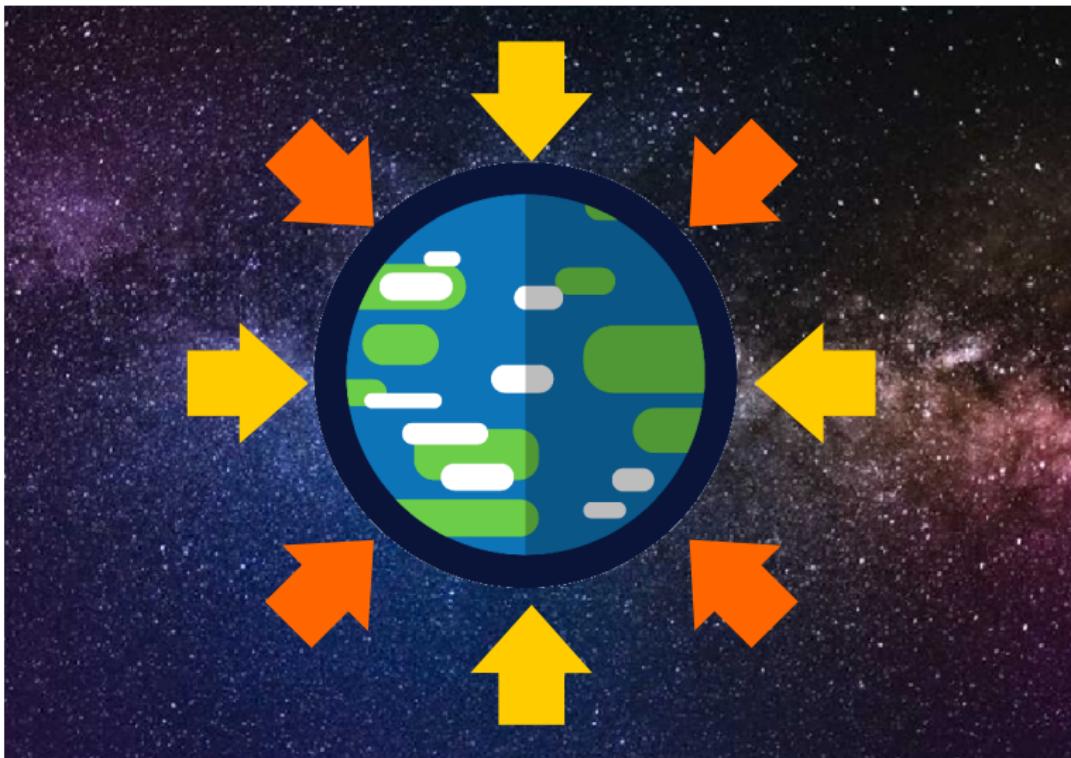
## Sudbury Neutrino Observatory (SNO)



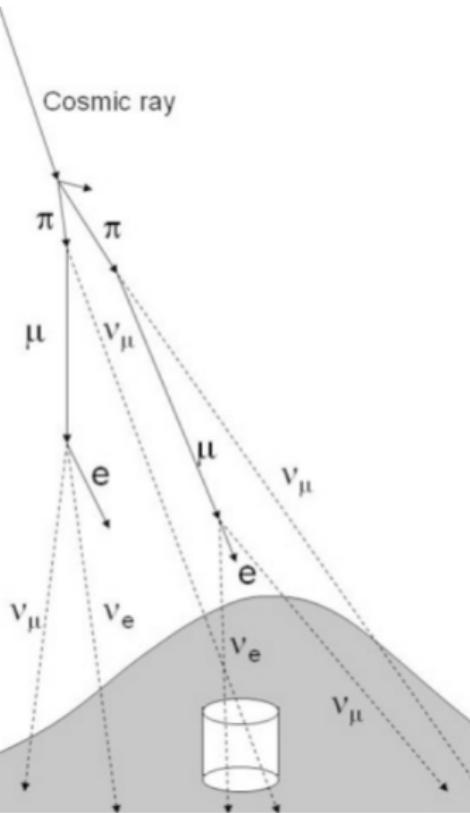
- 2.1 km underground
- filled with 1000 tonnes of heavy water
- sensitive to all neutrino flavors

SNO

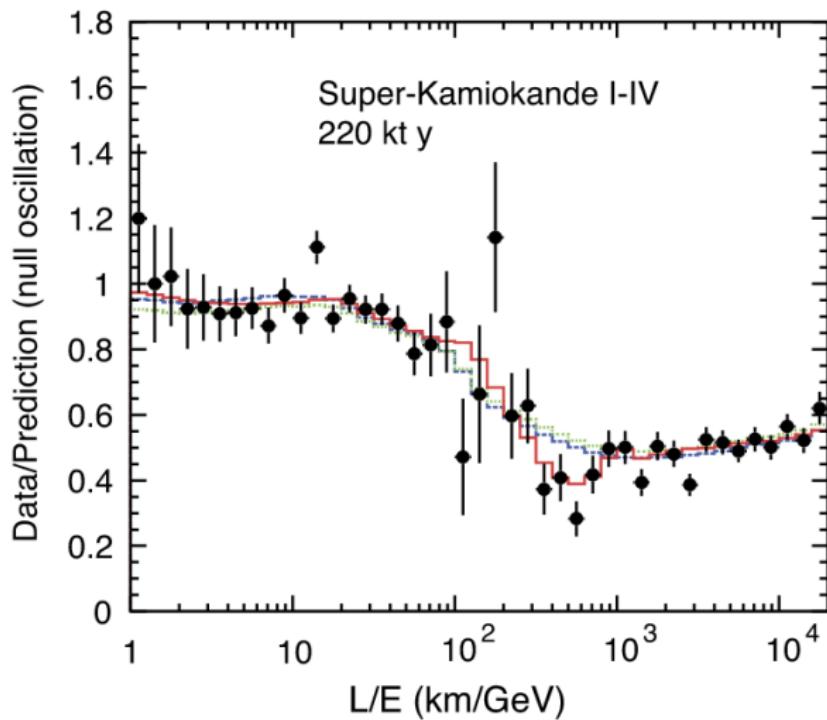
# Atmospheric neutrinos



# Atmospheric neutrinos



# Atmospheric neutrino problem



# Summary

- Neutrinos are weakly interacting elementary particles
- We are constantly bombarded by neutrinos from various sources, terrestrial: nuclear power plants, atmosphere, humans and extraterrestrials: Sun, Supernovae and other astrophysical objects
- Neutrinos have masses, that manifested their existence by neutrino oscillations
- Neutrino oscillate - change identity (flavor) as they propagate