Introduction to Neutrino

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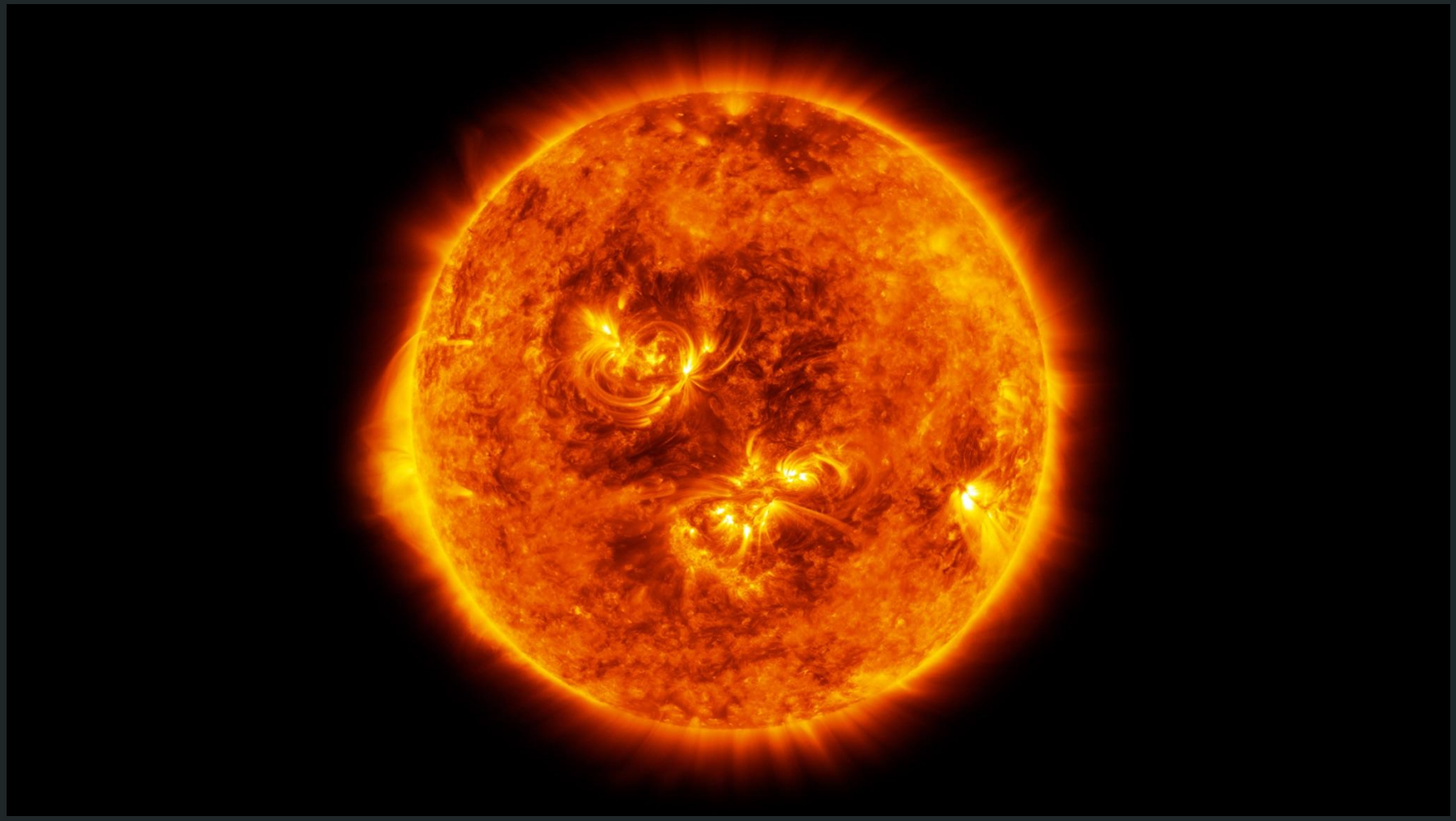
โครงการอบรมฟิสิกส์อนุภาคพื้นฐาน 2565

8 October 2022, Khon Kaen University

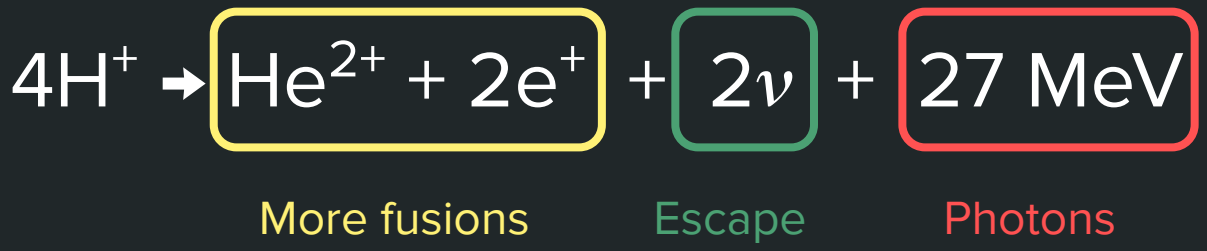
What are neutrinos?

The Sun



Cr: NASA Solar Dynamics Observatory

Nuclear fusion in the Sun



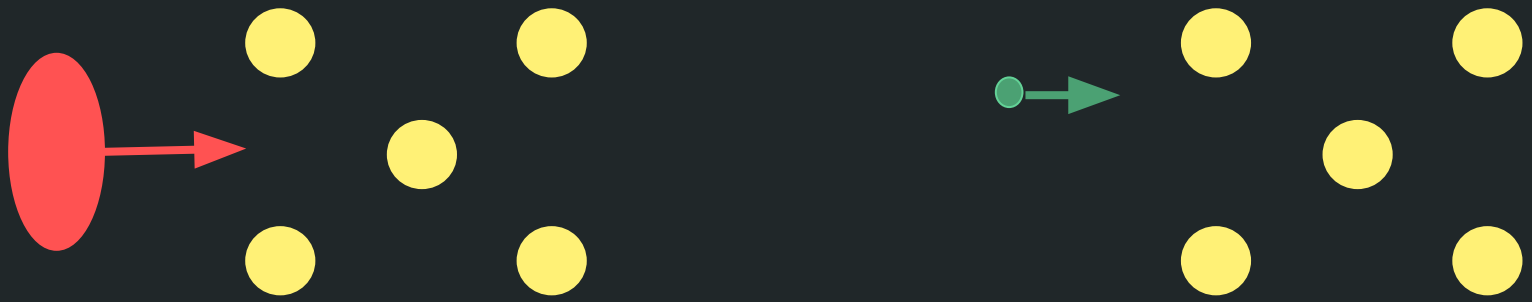
At the Earth

- About 10^{21} photons falling on your body every second
- About 10^{15} ν's falling on your body every second

We don't feel neutrinos, they just pass through us!

Cross-section

How likely is the particle going to go through?



Photons: Electromagnetic interactions, xsec ~ 10^{-24} cm^2

Neutrinos: Weak interactions, xsec ~ 10^{-38} cm^2

Neutrinos' xsec is much smaller than other known particles!

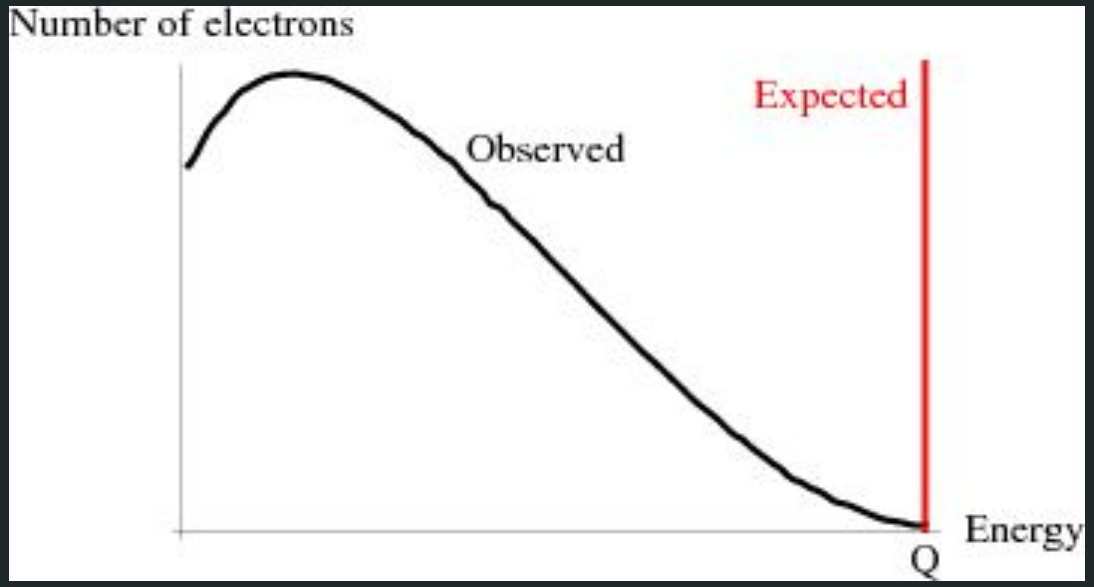
How neutrino was “discovered”?

“Nuclear beta decay” circa 1930 $N \rightarrow P + e^-$

- 1 → 2 process:
- Momentum conservation: $p_P = -p_e$
- Energy conservation completely determines E_e

What did we actually find?

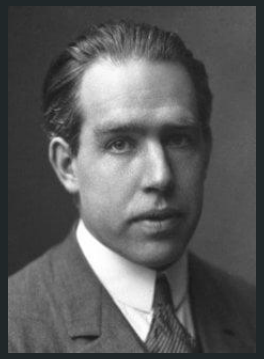
“Missing energy”



Cr: arXiv:1708.01046

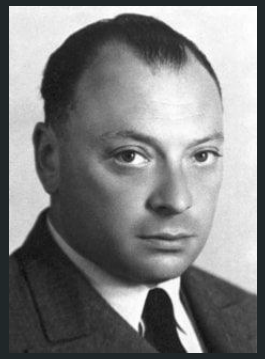
How to make sense of the “missing energy”?

Conservation laws are wrong!



N Bohr

1 → 2 process is wrong!



W Pauli

Cr: NobelPrize.org, PNGkey.com

Pauli's solution

The real beta decay

$$N \rightarrow P + e^- + \nu$$

- Charge conservation: ν must be neutral
- Mass "conservation": ν must be very light (almost massless)
- Only detect P and e^-: ν must interact very weakly

STANDARD WORKFLOW FOR "MYSTERY MANAGEMENT"

Mystery
(missing energy)

Guess
(new particle & interaction: neutrino & weak interaction)

Mathematical Model

Explains the mystery?
Yes?

Agrees with other observed phenomena?
Yes?

Other predictions?
Yes?
Found?

Images: Nobel.se

Borrowed from Pawin Ittisamai

How do we detect neutrino?

Need

- Neutrino sources
- Detectors

} not readily available in 1930s

$$\text{detection rate} = \underbrace{\text{flux} \cdot \text{xsec}}_{\text{(/target atom)}} \cdot N_A$$

Cowan and Reines first proposal

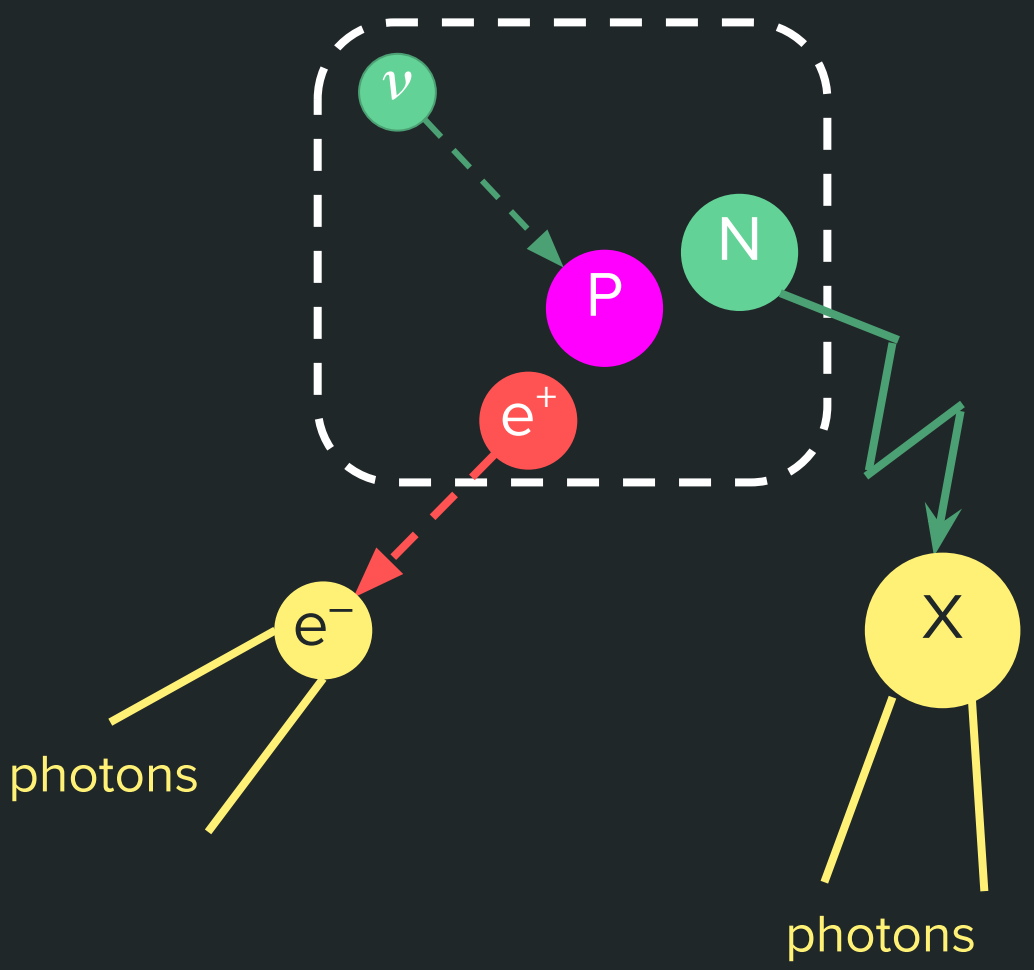
Cr: Istock

Cowan and Reines experiment (1956)

Savannah river site nuclear reactor

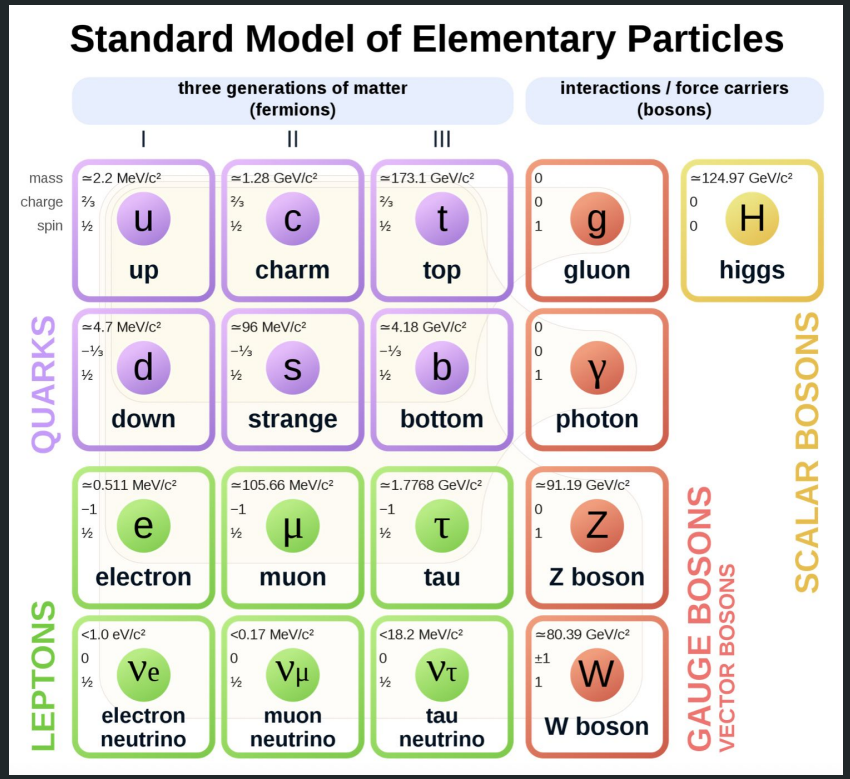
Cr: US Department of Energy

Inverse beta decay $\nu + P \rightarrow N + e^+$



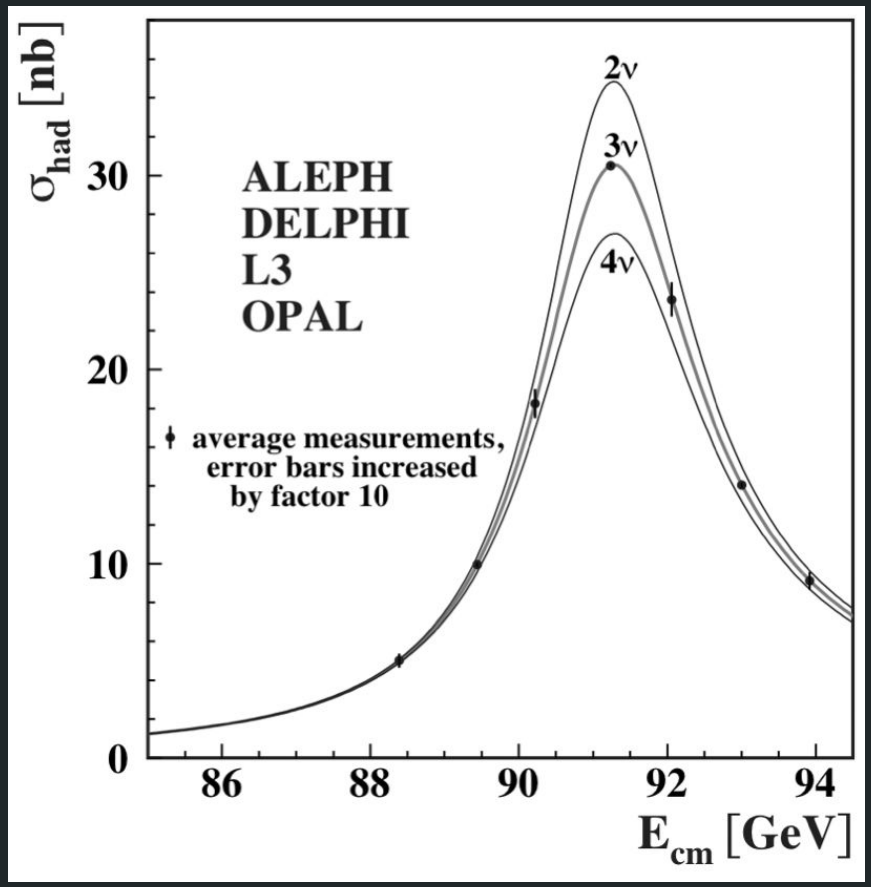
How many neutrinos are there?

Theory



Cr: Wikipedia

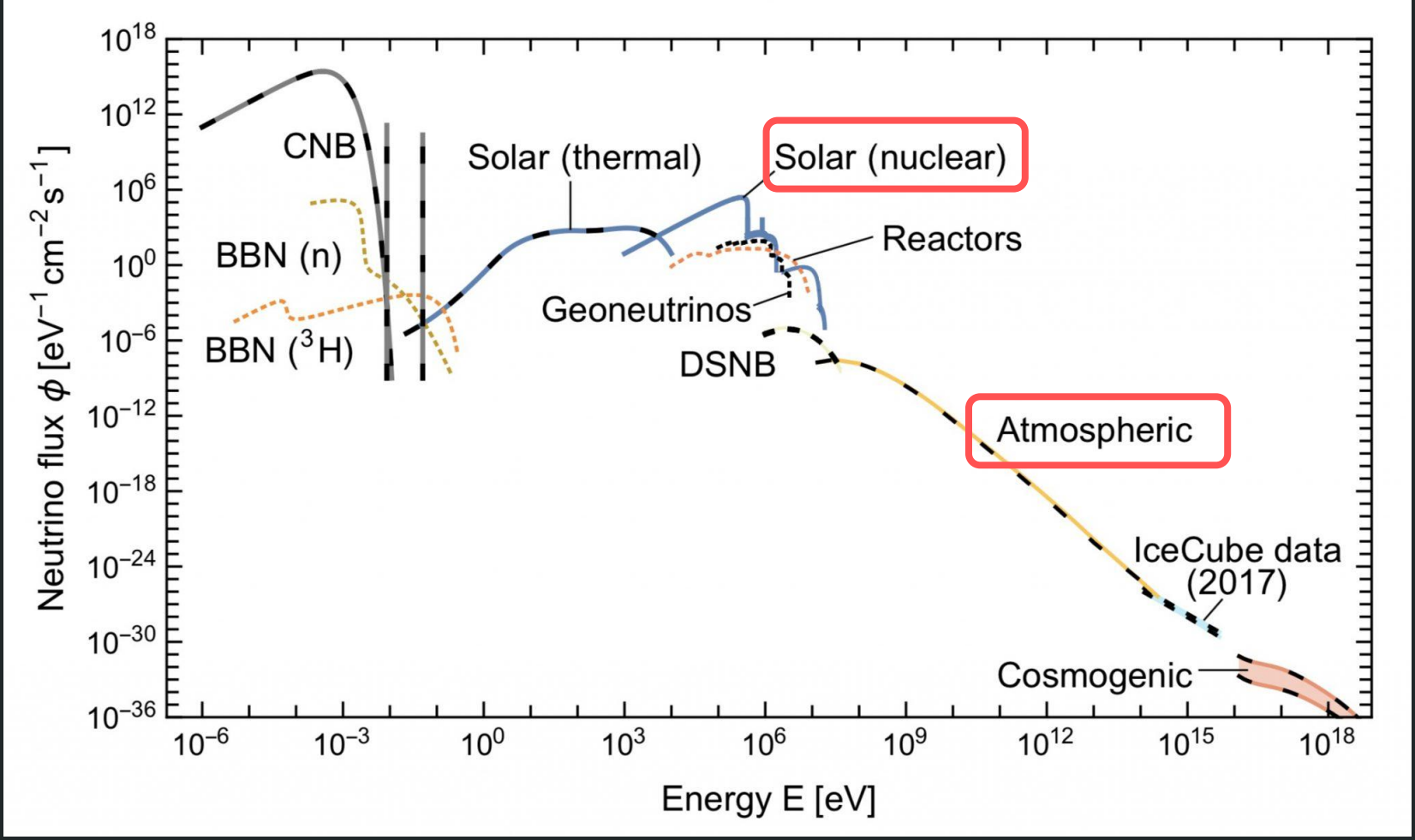
Experiment



Cr: CERN

Why do neutrinos matter?

The sources of neutrinos



Cr: arXiv:1910.11878

The solar neutrino problem

Homestake Experiment

- Goldmine in South Dakota
- 1500m underground
- 400m^3 of dry-cleaning fluid
- 1970 – 1994

Cr: US Department of Energy

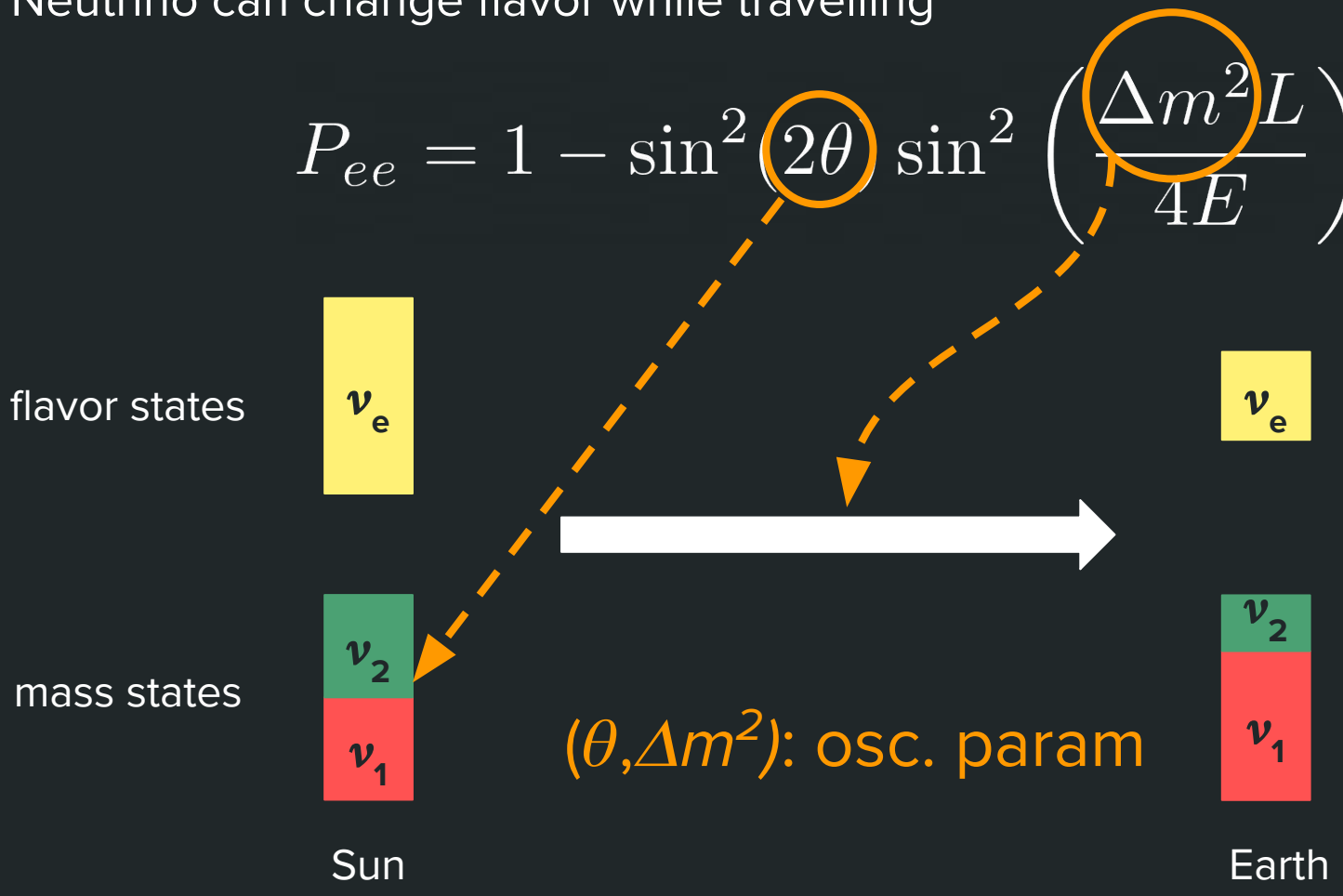
$$\nu_e + {}^{37}\mathrm{Cl} \rightarrow {}^{37}\mathrm{Ar} + e^-$$

Found only ⅓ of expected solar neutrino!

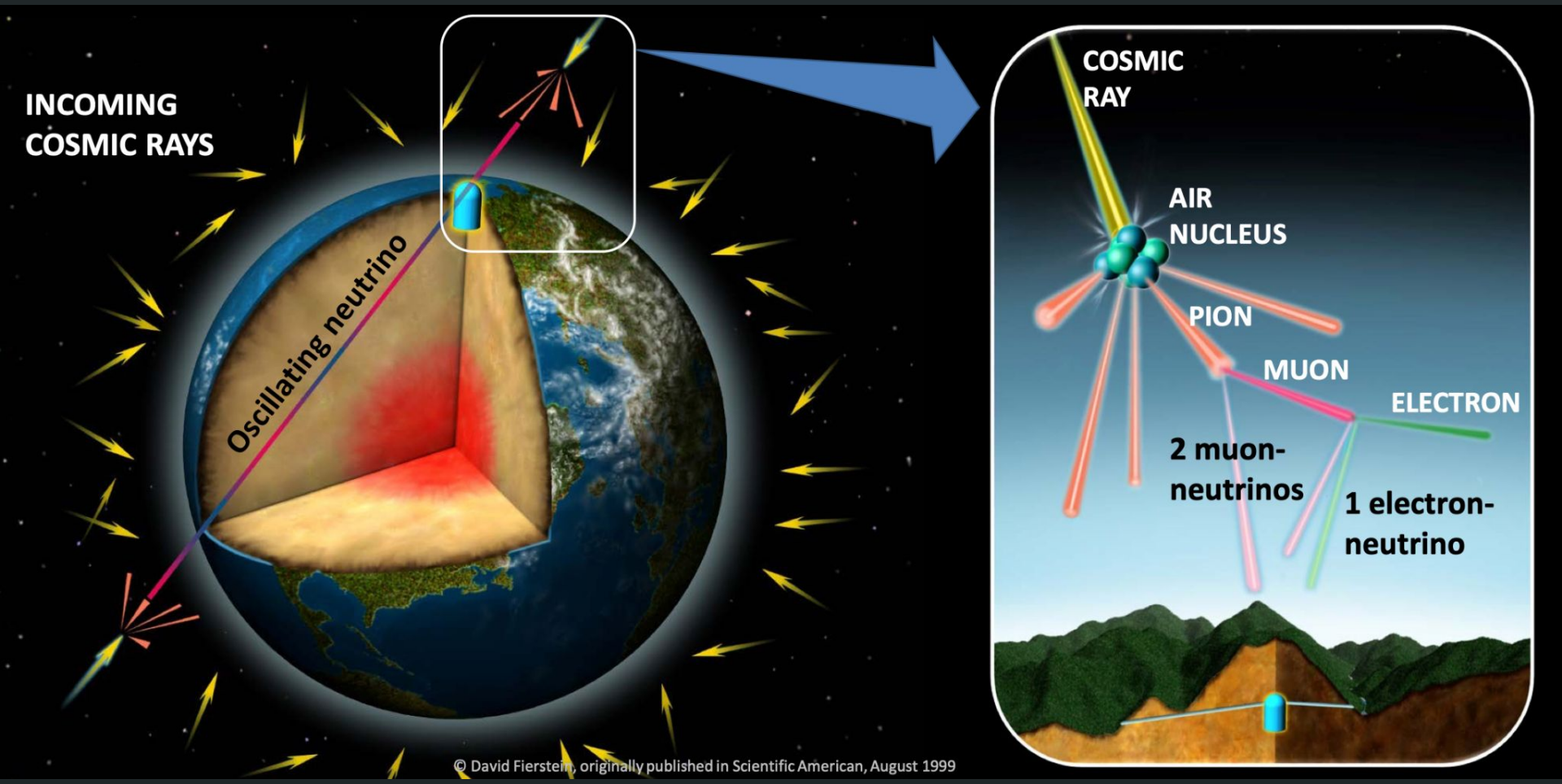
Neutrino oscillations

Neutrino can change flavor while travelling

$$P_{ee} = 1 - \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

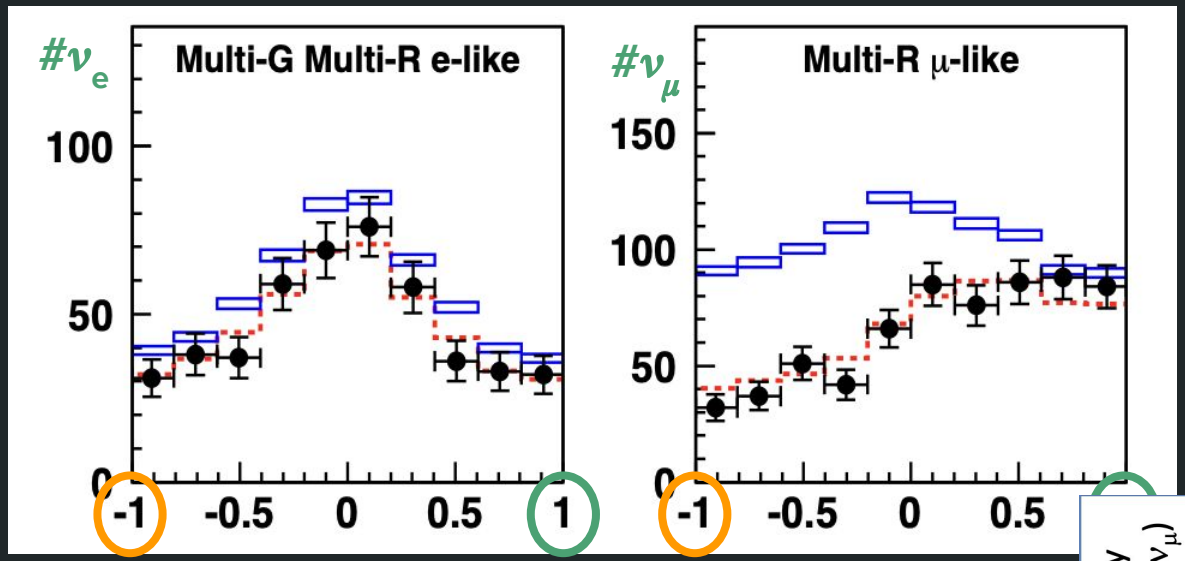


Atmospheric neutrinos



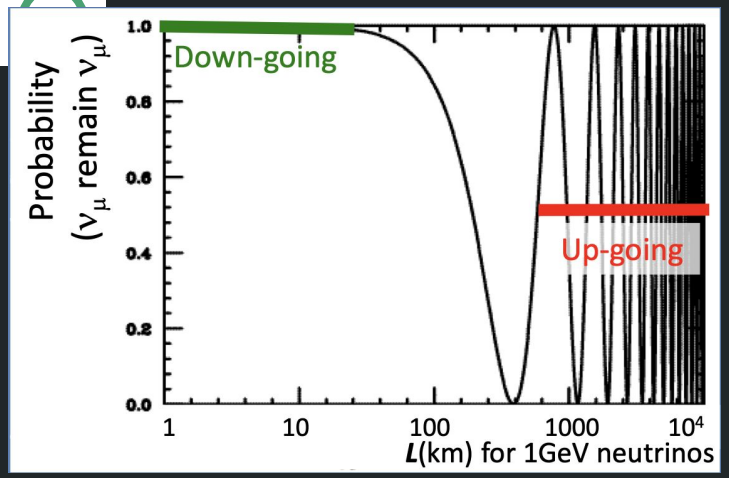
Cr: Takaaki Kajita, Nobel Lecture 2015

Atmospheric neutrinos problems



Upgoing **Downgoing**

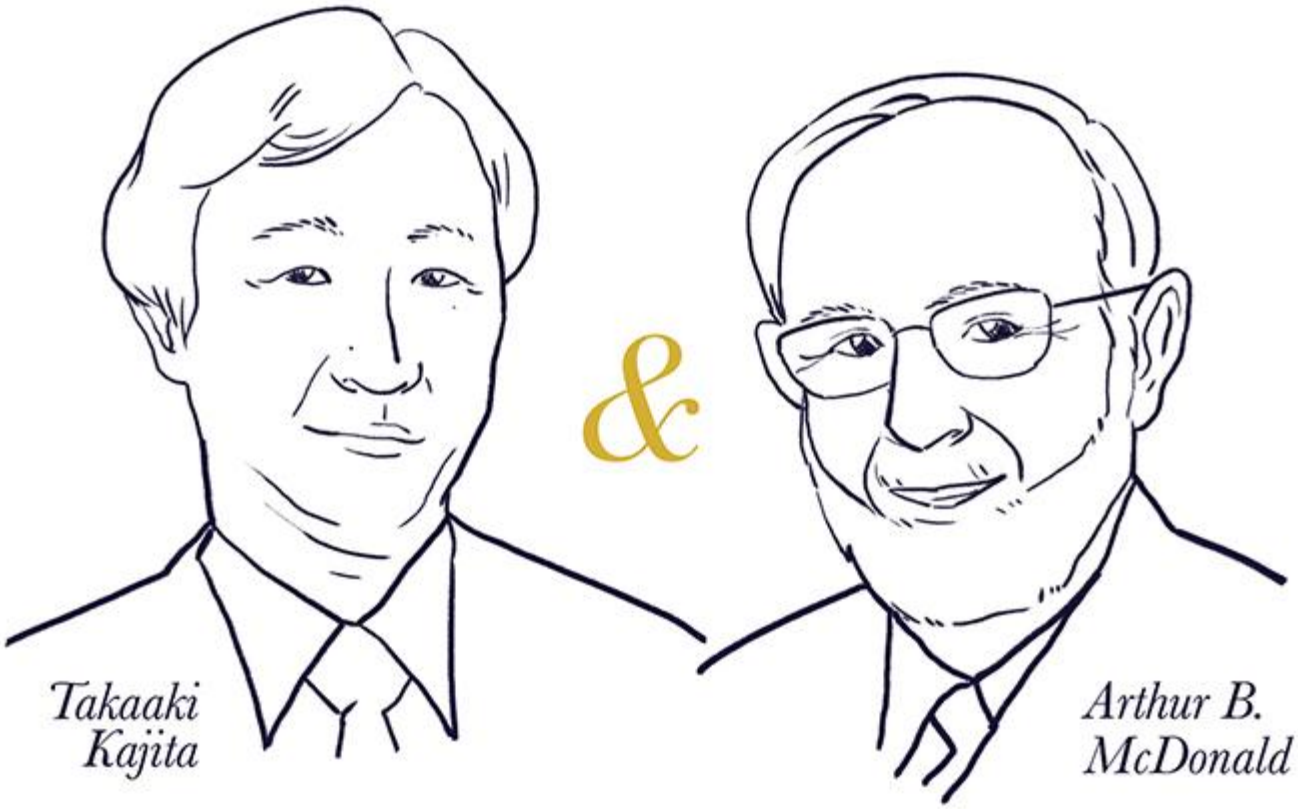
Cr: arXiv hep-ex/0604011



Cr: T. Kajita, Nobel Lecture 2015

ν_μ osc. is different from ν_e osc.

2015 NOBEL PRIZE *in Physics*



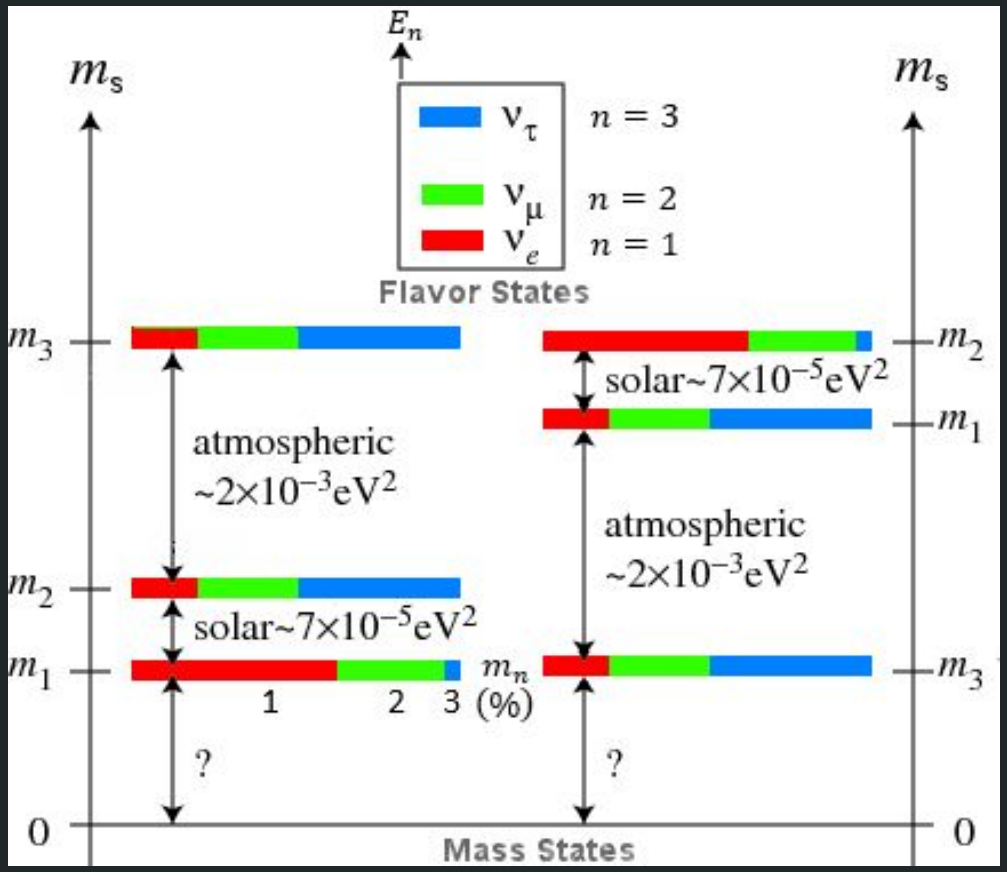
NEUTRINO OSCILLATIONS

The discovery of these oscillations shows that neutrinos have mass.

Image by Abigail Malate

AIP INSIDE SCIENCE

Current status of neutrino oscillations



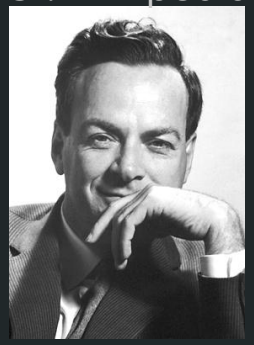
At least two
massive neutrinos!

Cr: Universe Review

So neutrinos are massive.
Big deal?

Richard Feynman (1918-1988)

Cr: Wikipedia

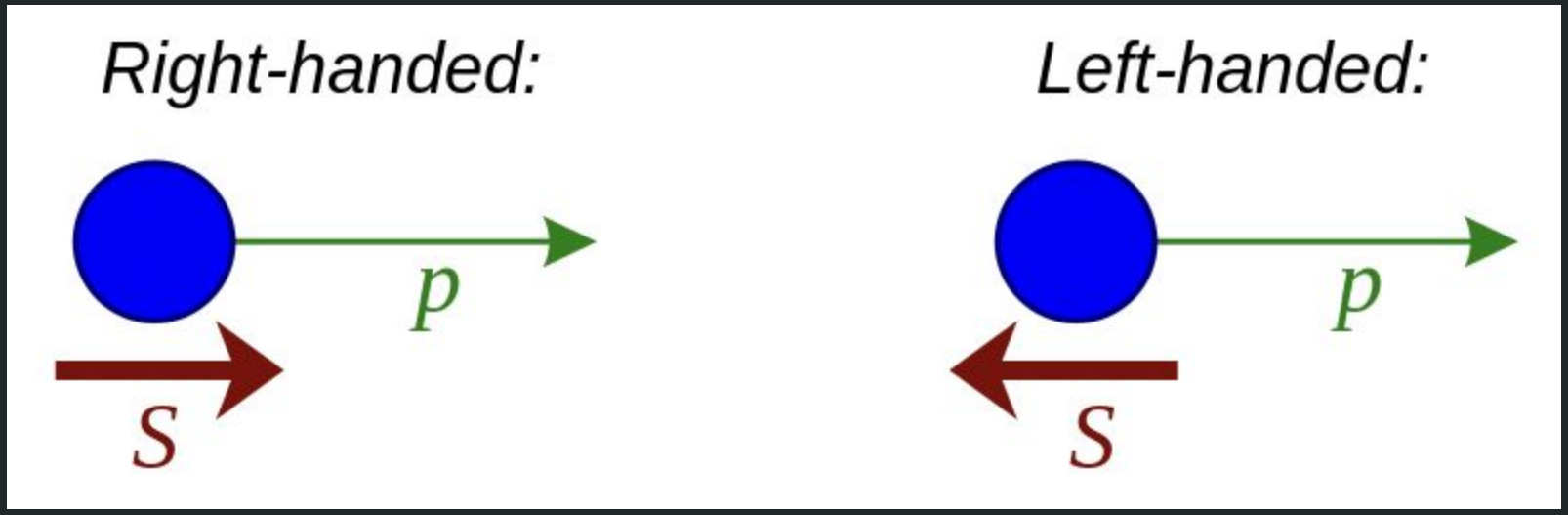


"We never are definitely right, we can only be sure we are wrong!"

Implication of a massive neutrino

Cr: Symmetry Magazine

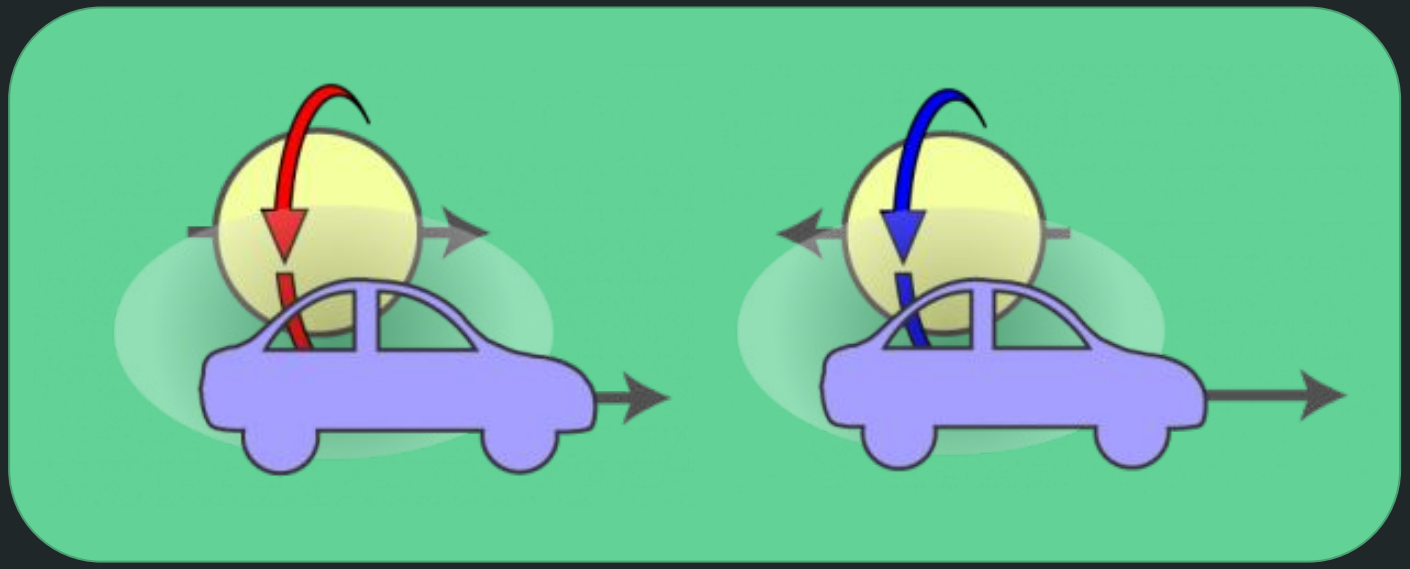
Chirality



Cr: Wikipedia

Chirality and relativity

- Massive particle contains both left and right chirality



- Massless particle only has one chirality
  - “We cannot catch up with light”
  - What does this imply for neutrinos?

Fermions in the Standard Model

Quarks

$$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$$

$u_R \quad d_R$

Leptons

$$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$$

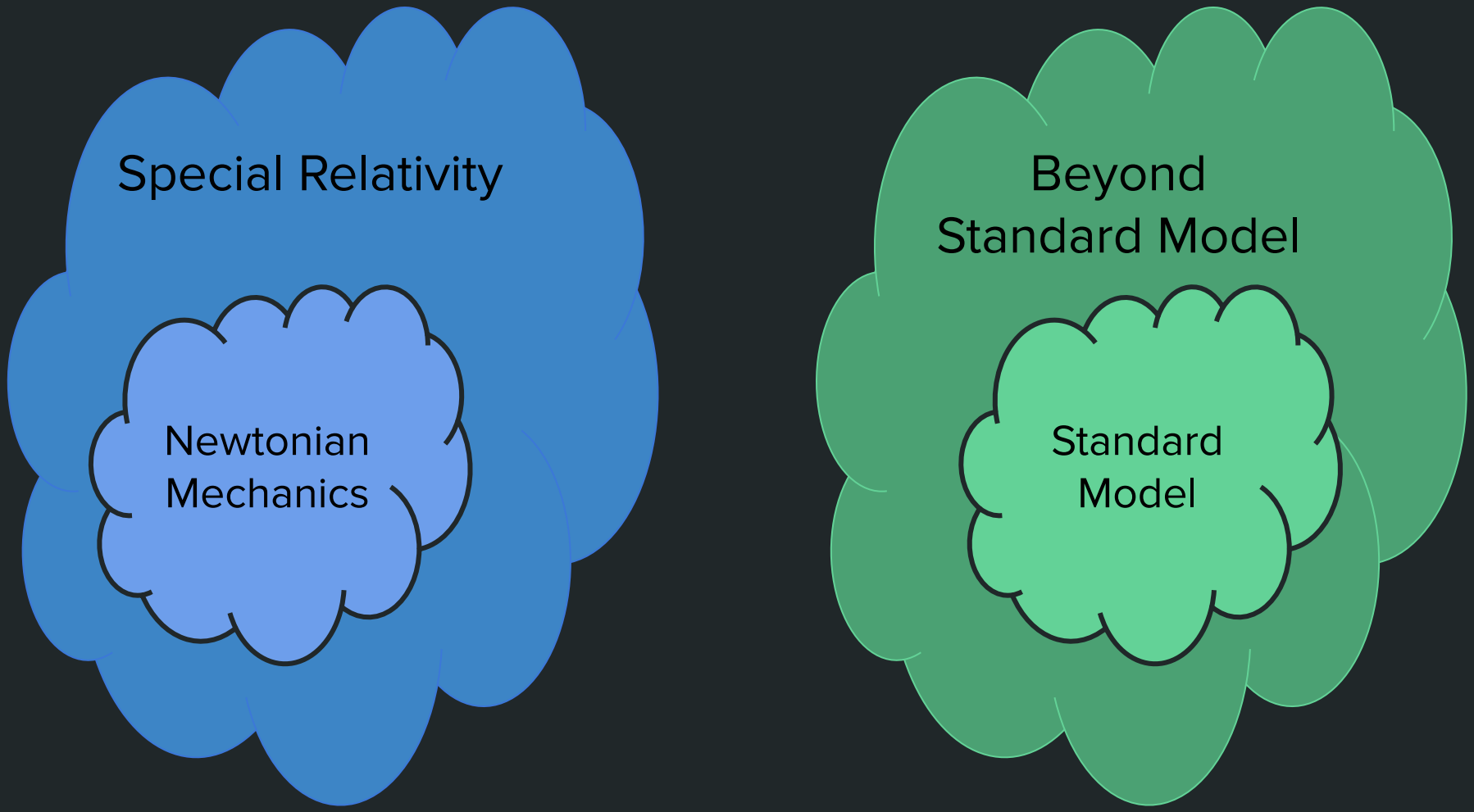
e_R

“The Standard Model contains only left-handed neutrinos, so they must be massless!”

Is a wrong theory any good?

Standard Model

Domain of validity



Massive neutrino means we need to extend the Standard Model

New physics is out there

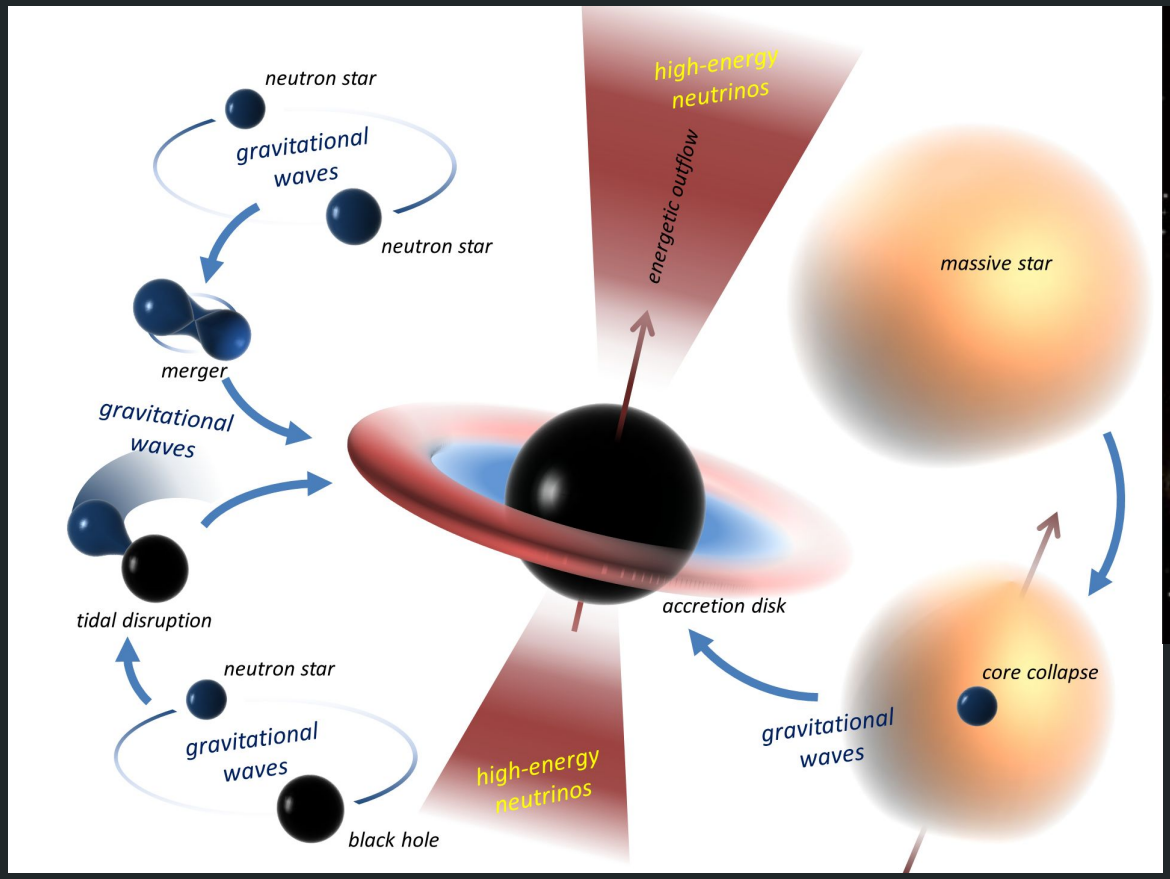
Open questions for neutrino physics

- How do neutrinos get their mass?
  - Theory (easy)
  - Discovery (hard)
- What are neutrino masses ordered?
- How many neutrinos are there?
  - 3 active. Sterile?
- Are neutrinos connected to other unknown physics?
  - Dark matter?
  - Baryogenesis?

...

Why should we care about neutrinos?

Multi-messenger astronomy



Cr: arXiv 1212.2289

Cr: NASA, ESA, J Hester, A Loll

Submarine Navigation using Neutrinos

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Abstract

Neutrinos are among the most abundant particles in the universe, nearly massless, travel at speeds near the speed of light and are electrically neutral. Neutrinos can be generated through man-made sources like particle accelerators or by natural sources like the sun. Neutrinos only interact via the weak force and gravity. Since gravitational interaction is extremely weak and the weak force has a very short range, neutrinos can travel long distances unimpeded through matter, reaching places inaccessible to GNSS (Global Navigation Satellite System) signals such as underwater locations. The main objective of this work is to sketch an early high-level design of a Neutrino PNT (Position, Navigation and Timing) mission and analyze its feasibility for submarine navigation since there is a need to improve current navigation technologies for submarines. The high-level preliminary concept proposes Cyclotrons or Linear Accelerators based on the physical process Pion Decay at Rest as neutrino sources. For detecting such isotropic neutrino fluxes user equipment must be composed of a high-performance clock synchronized with the system, a detector and possibly additional sensors such as IMU (Inertial Measurement Unit). A feasibility analysis of the recommended system option is performed based on simulations for determining the neutrino detection rate and on a PNT tool to estimate the PNT performances. Although the submarine navigation application is in the limit of being feasible with current technology, it could be realized with some important but reasonable progress in source and neutrino detector technology.

Keywords: Navigation, Neutrinos, Positioning, Submarine, Underwater communication

Neutrino research in Thailand

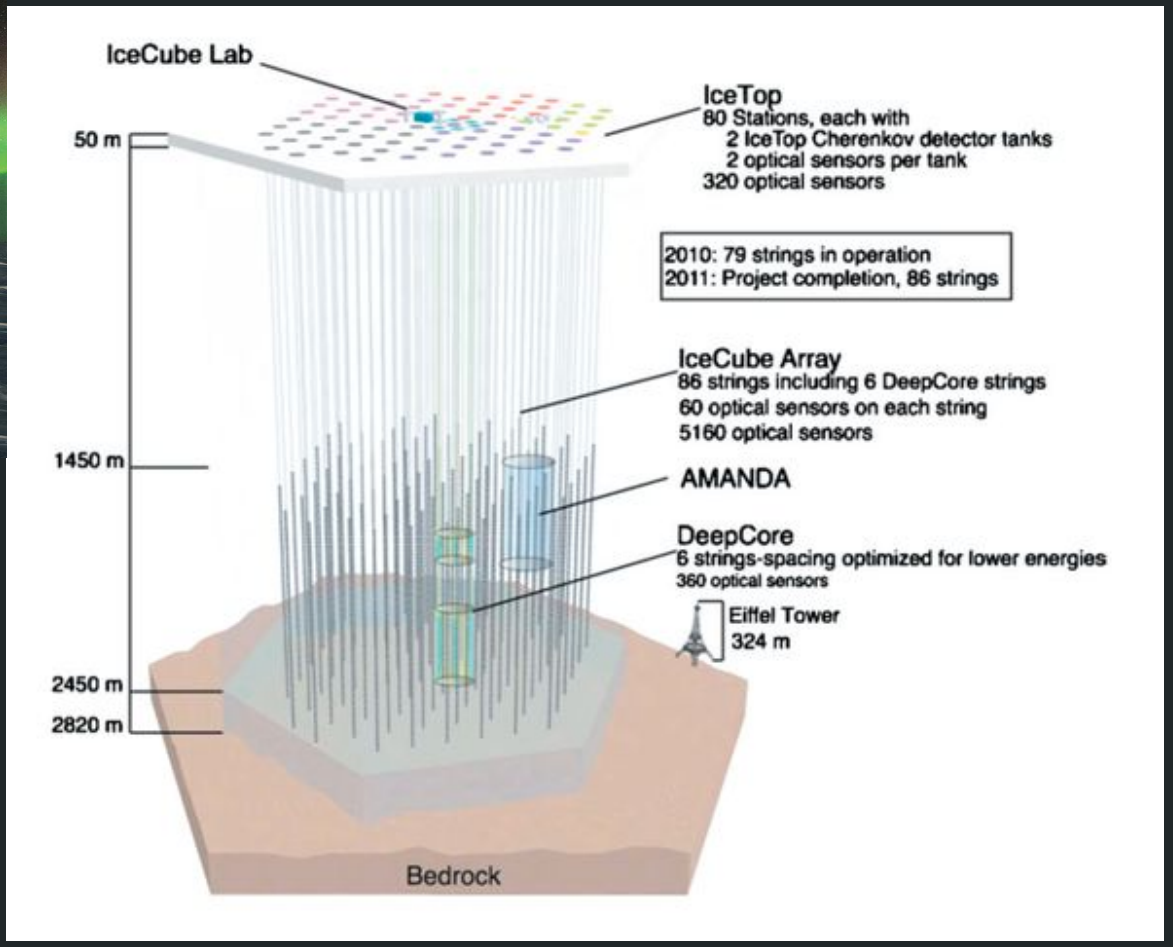
Chiang Mai U
(IceCUBE)
NARIT
(JUNO)

Khon Kaen U
(Pheno)

Chulalongkorn
(KATRIN, JUNO,
IceCUBE, pheno)
Srinakharinwirot U
(Pheno)

Suranaree U,
(KATRIN, JUNO)

IceCUBE



Cr: IceCUBE Collaboration

Thai @ IceCUBE

Achara (NARIT)

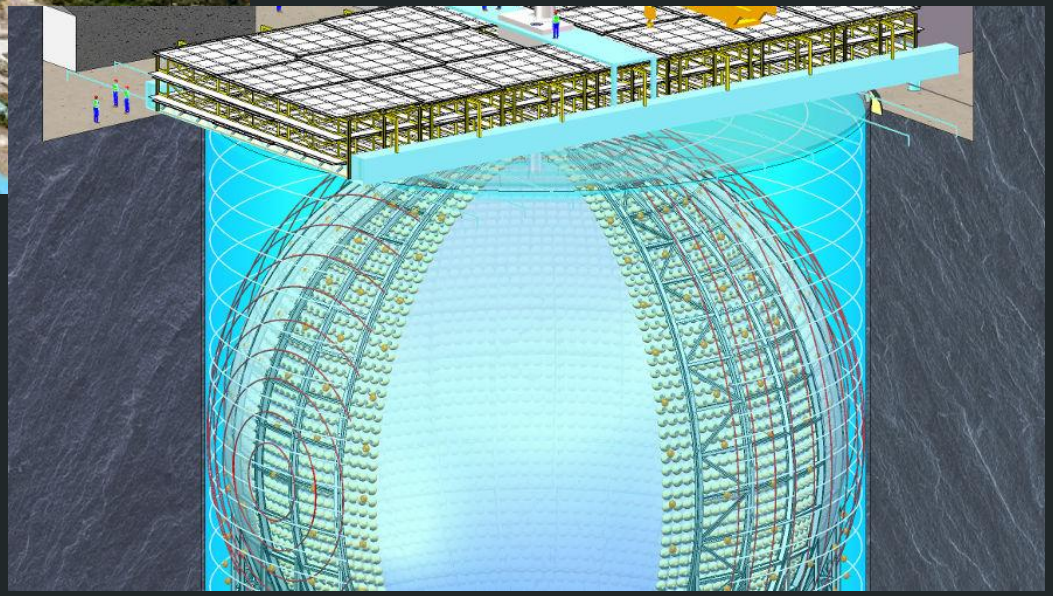
Chayanit (CU)

Waraporn (CMU)

- Work on IceTop detector
- Study atmospheric and astrophysical neutrinos

Jiangmen Underground Neutrino Observatory

Cr: Liu Dawei, *Alamy*



Cr: JUNO Collaboration

Thai @ JUNO

SUT

Ayut Chinorat Khanchai Warintorn

- Study background B field in the detector tank

Narumon (CU)

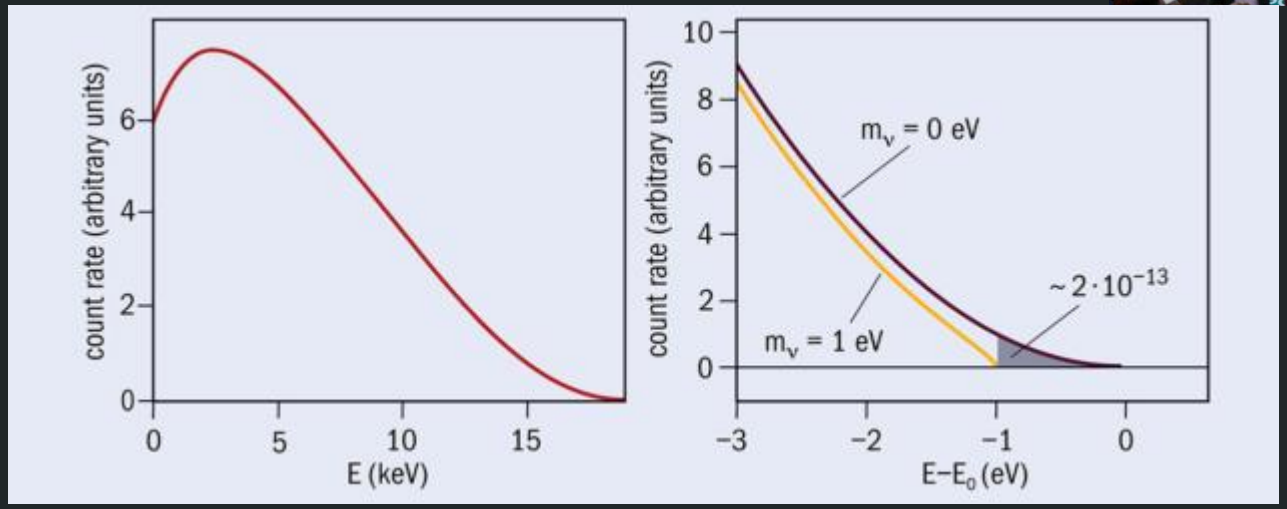
Utane (NARIT)

- Data analysis
- Search for dark matter annihilate into neutrinos

Karlsruhe Tritium Neutrino Experiment

Directly measure ν_e “mass” from tritium beta decay

Cr: KIT



Cr: CERN

Thai @ KATRIN

SUT

Ayut Chinorat Khanchai Warintorn

- Develop B field sensor
- Simulate B field for next generation experiment

Chula

Auttakit

Narumon

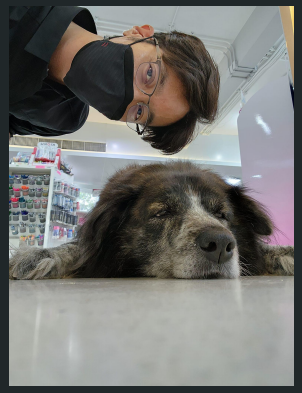
Udomsilp

- Data analysis for sterile neutrino search

Thai neutrino phenology

Chakrit (KKU)

Patipan (SWU)



Pawin (CU)

- Neutrino mass model
- Connection between neutrinos and dark matter

Khon Kaen Particle Physics and Cosmology Theory

[KKPaCT]

“เราจะเป็นศูนย์ฟิสิกส์ทฤษฎีที่ดีที่สุดอันดับสามของประเทศ”

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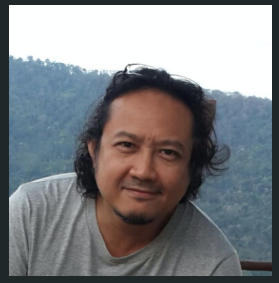
THEPA Team

Particle Physics

Patipan Uttayarat

BSM physics



Kem Poomsa-ard

Quark Model

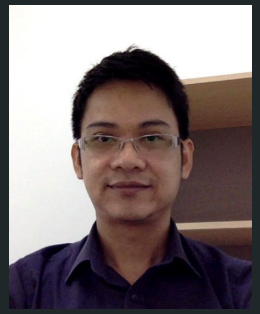
Nopmanee Supanam

Chiral Perturbation

Black Hole Physics

Suphot Musiri

Quasi-normal mode



Wasutep Luangtip

ULX physics

3 grad students + 3 undergrad

We’re recruiting!!!