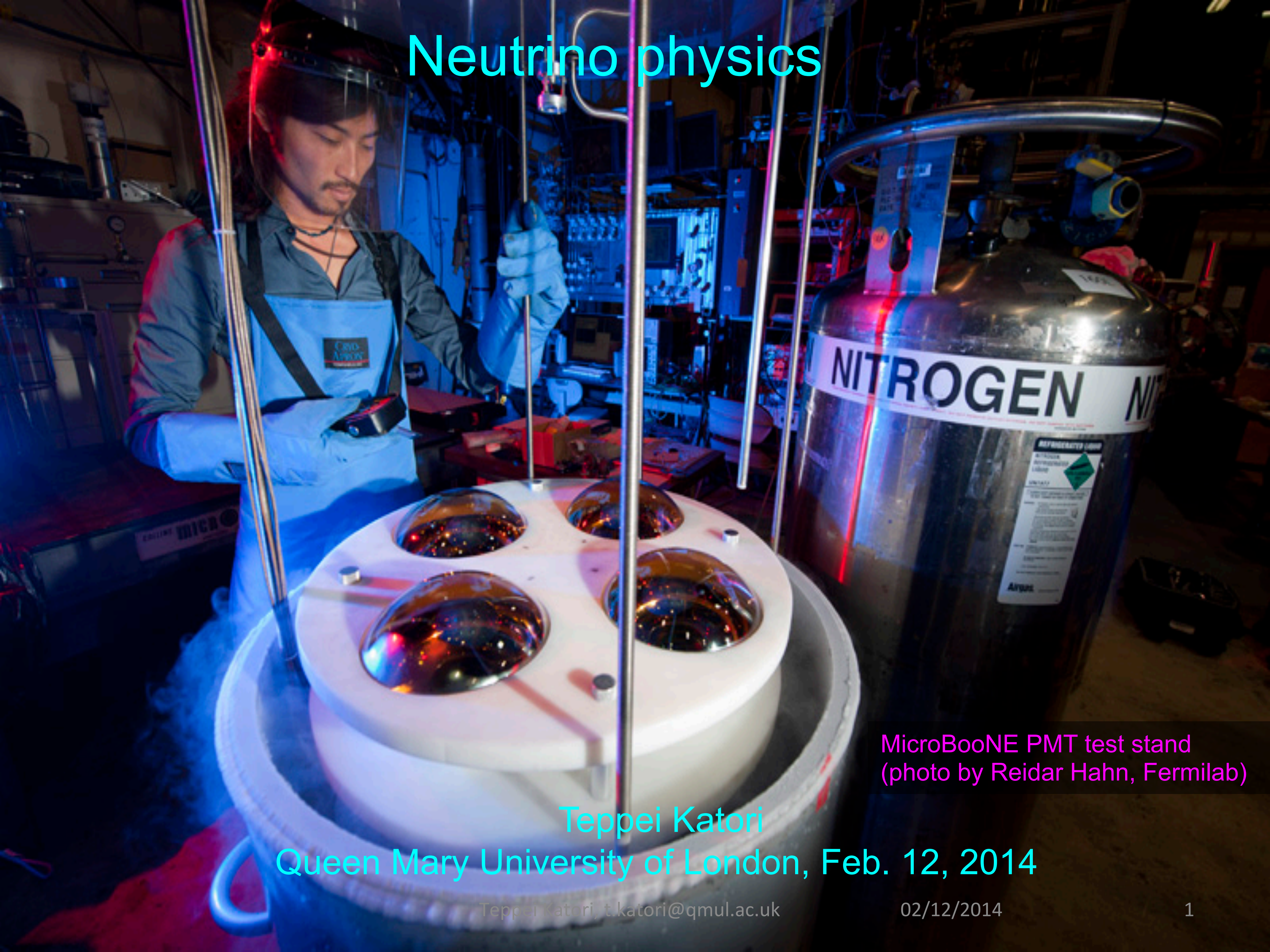
Neutrino physics



MicroBooNE PMT test stand
(photo by Reidar Hahn, Fermilab)

Teppei Katori
Queen Mary University of London, Feb. 12, 2014

Neutrino physics

Hi, my name is Teppei Katori, I am a lecturer, and a particle physicist
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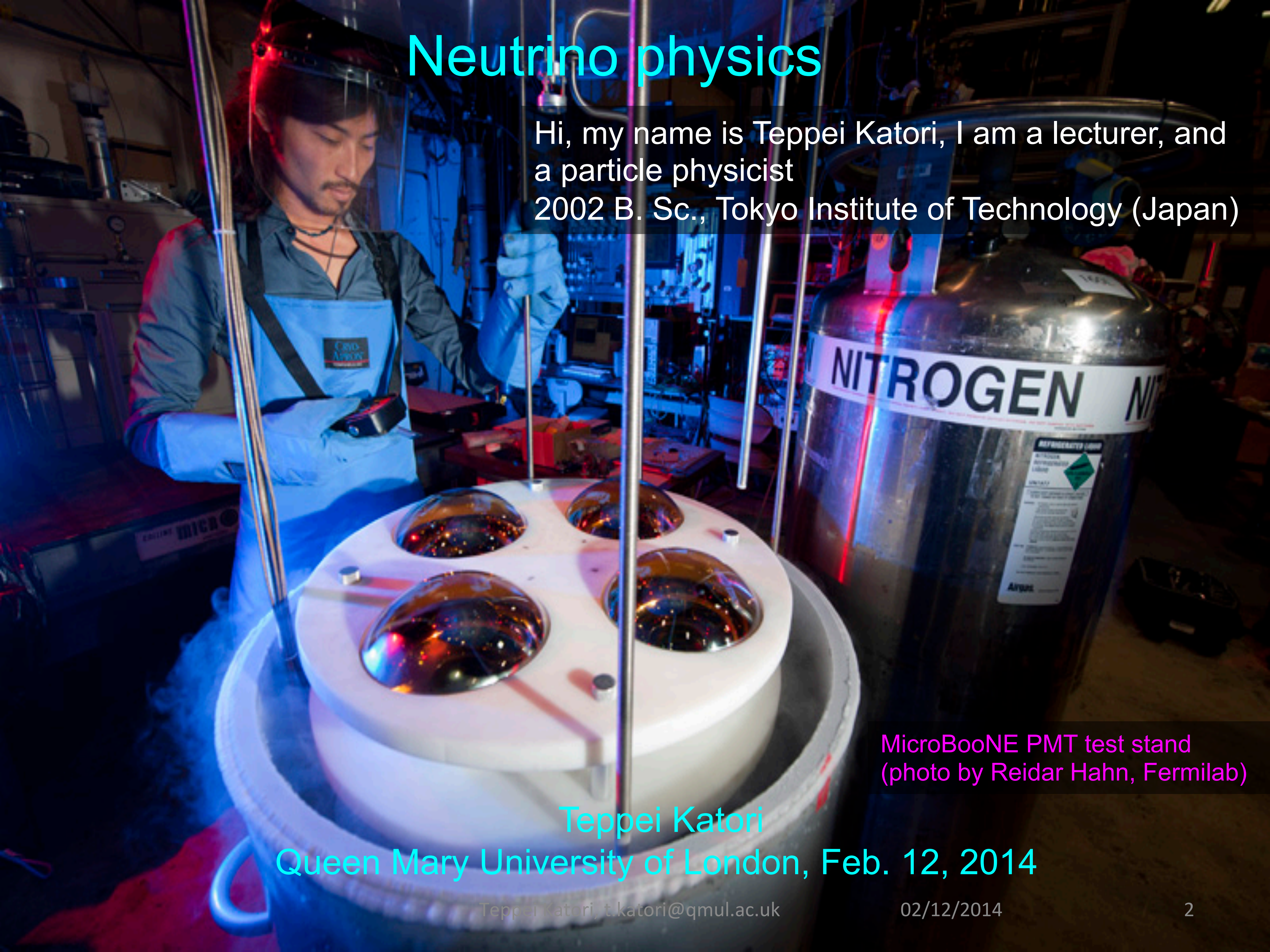

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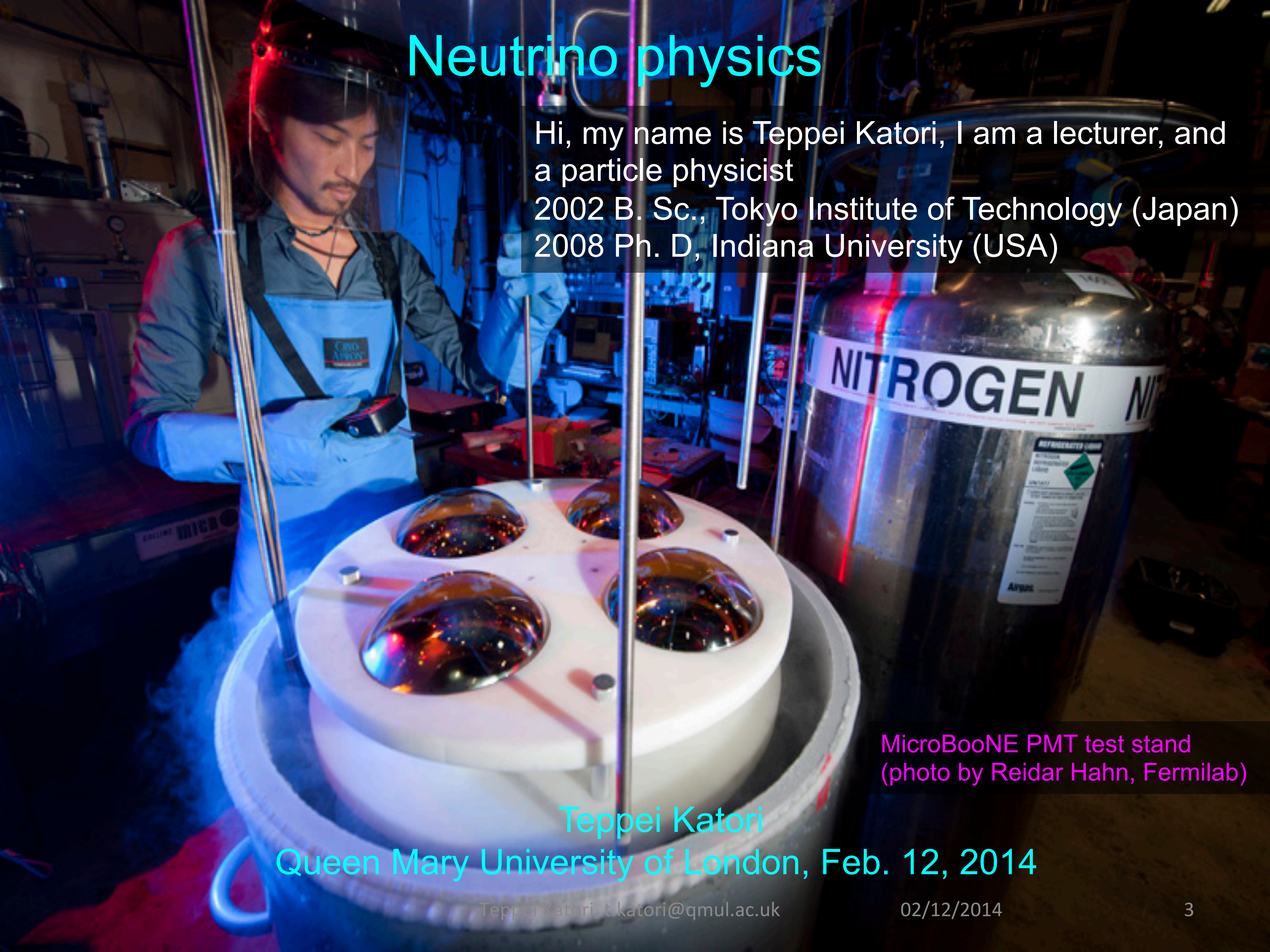

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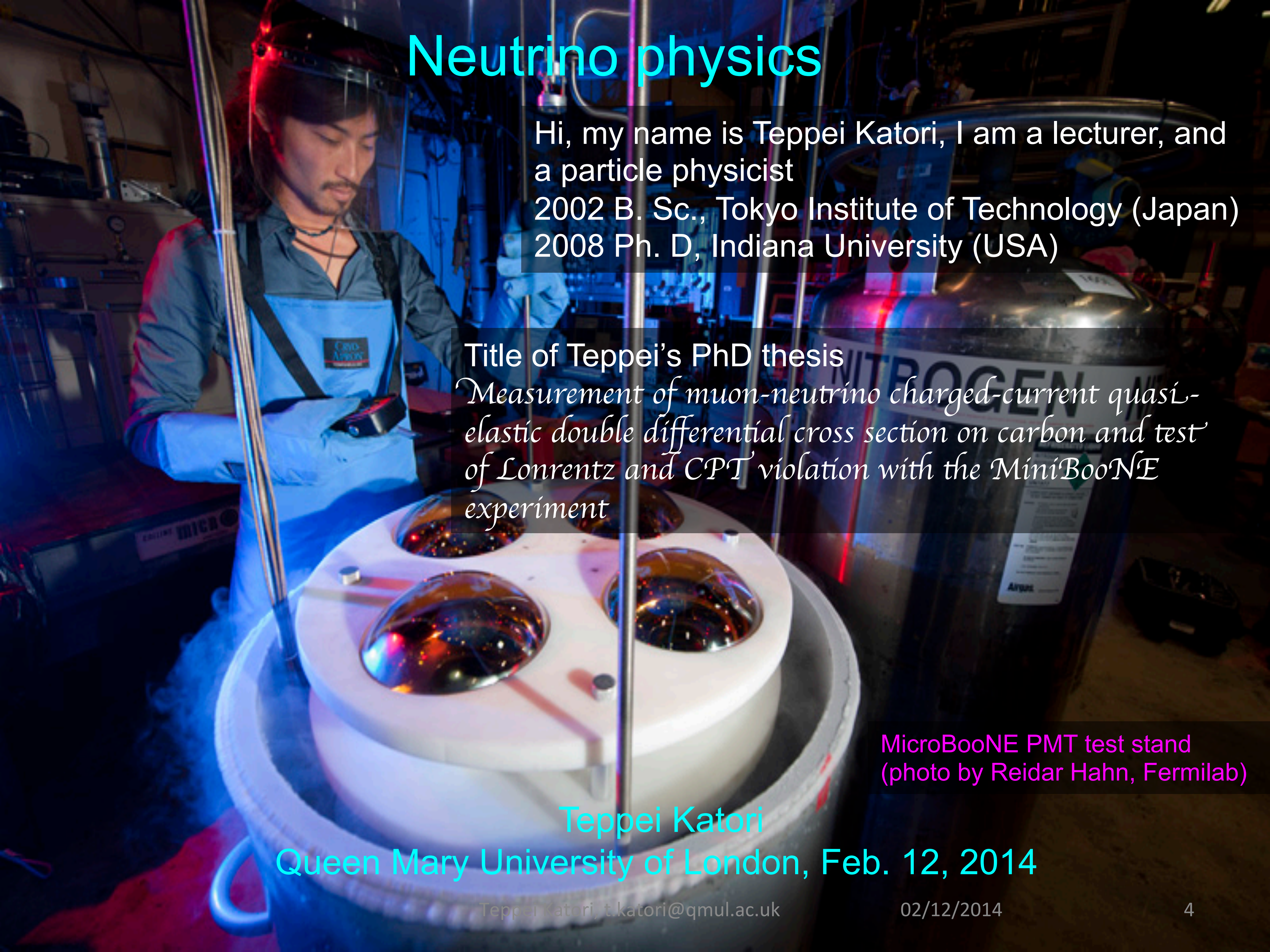

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Title of Teppei's PhD thesis
Measurement of muon-neutrino charged-current quasi-elastic double differential cross section on carbon and test of Lonrentz and CPT violation with the MiniBooNE experiment

MicroBooNE PMT test stand
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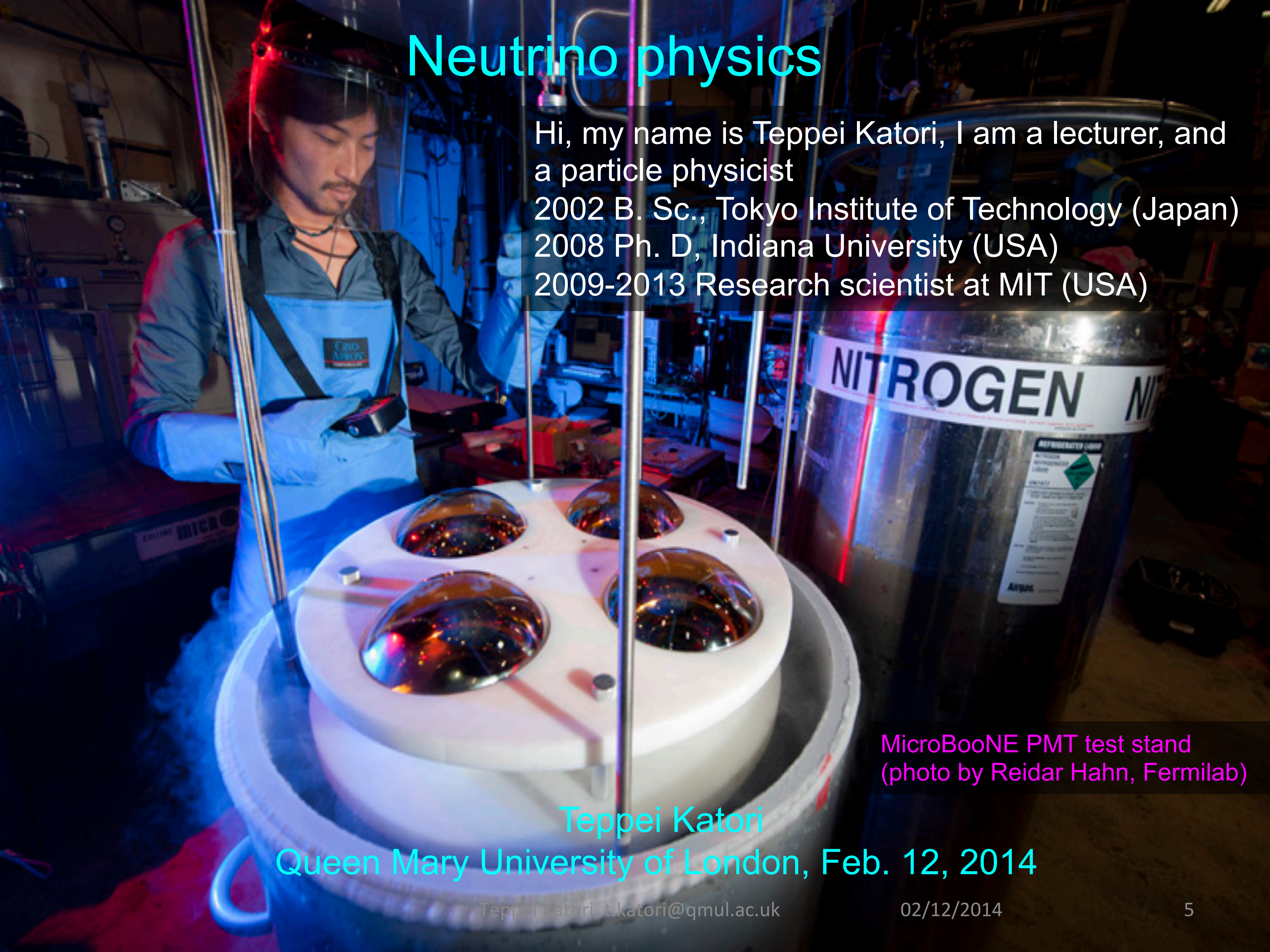

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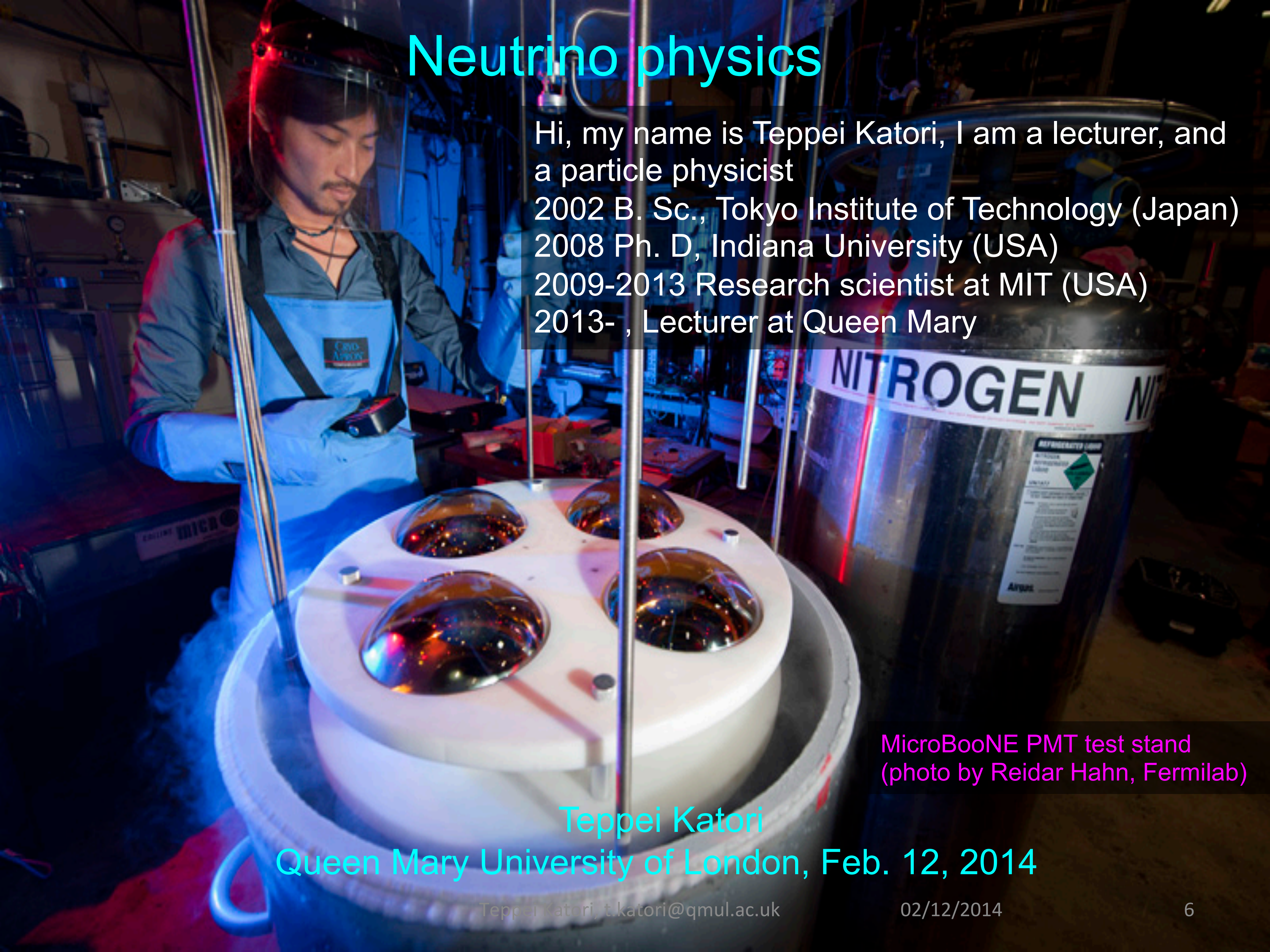

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Where is Physics? Everywhere!

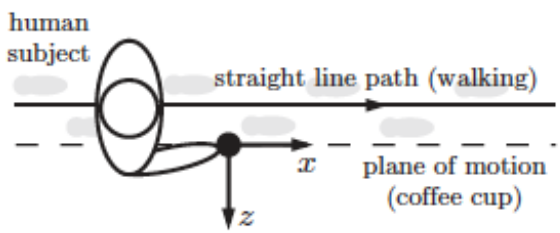
Physics is the subject to study the laws of Nature
- Every phenomenon in Nature are subject of physics laws

Some examples

Where is Physics? Everywhere!

Physics is the subject to study the laws of Nature
- Every phenomenon in the Nature are subject of physics laws

Physics can find the best way to walk with coffee cup without spilling



(a)

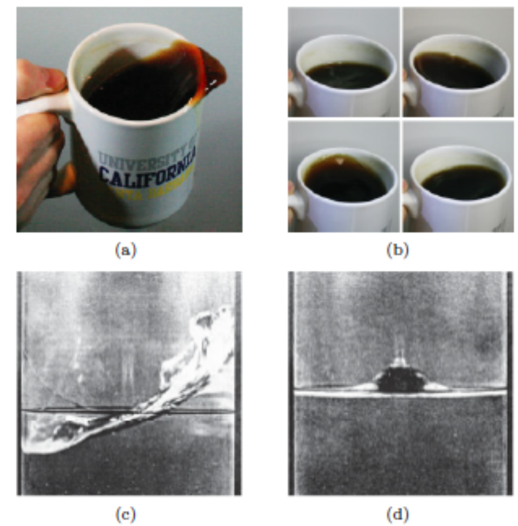


FIG. 1. (Color online) Coffee spill and key liquid motions in an excited cup. (a) Representative image of coffee spilling. (b) Rotational liquid motion in clockwise direction: top left–top right–bottom left–bottom right. (c) Back-and-forth liquid oscillations (photograph from [1]). (d) Vertical liquid oscillations (photograph from [1]).

PHYSICAL REVIEW E 85, 046117 (2012)

Walking with coffee: Why does it spill?

H. C. Mayer and R. Krechetnikov
Department of Mechanical Engineering, University of California, Santa Barbara, California 93106, USA
(Received 23 December 2011; published 26 April 2012)

In our busy lives, almost all of us have to walk with a cup of coffee. While often we spill the drink, this familiar phenomenon has never been explored systematically. Here we report on the results of an experimental study of the conditions under which coffee spills for various walking speeds and initial liquid levels in the cup. These observations are analyzed from the dynamical systems and fluid mechanics viewpoints as well as with the help of a model developed here. Particularities of the common cup sizes, the coffee properties, and the

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PRL 107, 258101 (2011) PHYSICAL REVIEW LETTERS week ending 16 DECEMBER 2011

Leonardo's Rule, Self-Similarity, and Wind-Induced Stresses in Trees

Christophe Eloy*

Department of Mechanical and Aerospace Engineering, University of California San Diego, 9500 Gilman Drive, La Jolla California 92093-0411, USA

(Received 12 May 2011; published 12 December 2011)

Examining botanical trees, Leonardo da Vinci noted that the total cross section of branches is conserved across branching nodes. In this Letter, it is proposed that this rule is a consequence of the tree skeleton :h diameters being adjusted to resist wind-induced loads.

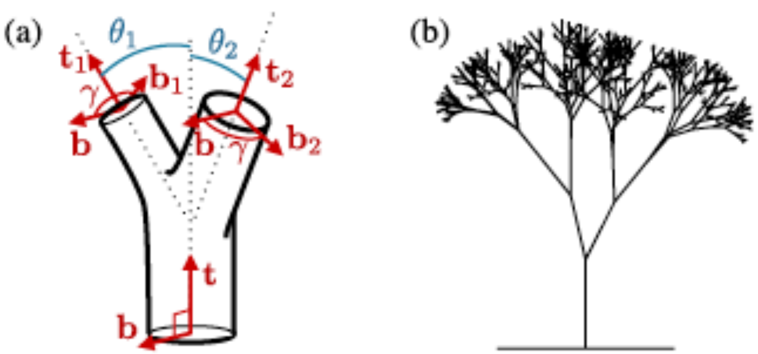

FIG. 2 (color online). Numerical tree model: (a) Sketch of the angles and unit vectors at a branching node. (b) Example of tree skeleton for $\theta_1 = -15°$, $\theta_2 = 30°$, $\gamma = 120°$, $r_1 = r_2 = 0.75$, $p = 1$, $K = 10$, $D = 2.41$ [as given by (9)].

Physics can explain why tree looks like a tree

Where is Physics? Everywhere!

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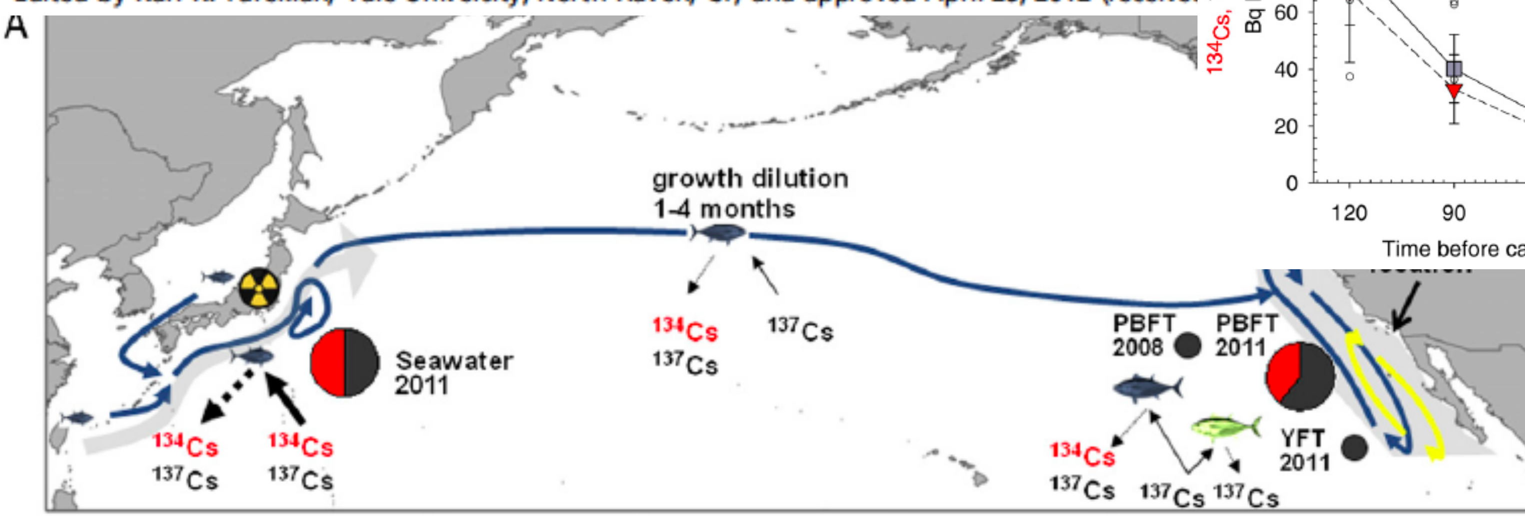
Physicists aren't afraid radioactive sushi, because it's not

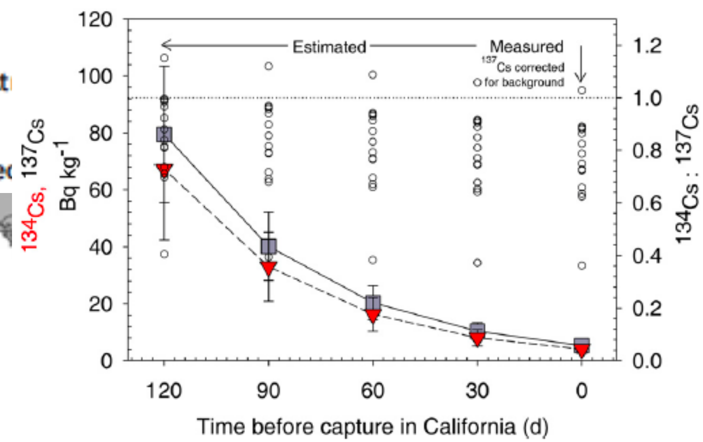
Pacific bluefin tuna transport Fukushima-derived radionuclides from Japan to California

Daniel J. Madigan[a,1], Zofia Baumann[b], and Nicholas S. Fisher[b]

[a]Hopkins Marine Station, Stanford University, Pacific Grove, CA 93950; and [b]School of Marine and At
NY 11794

Edited by Karl K. Turekian, Yale University, North Haven, CT, and approved April 25, 2012 (receive





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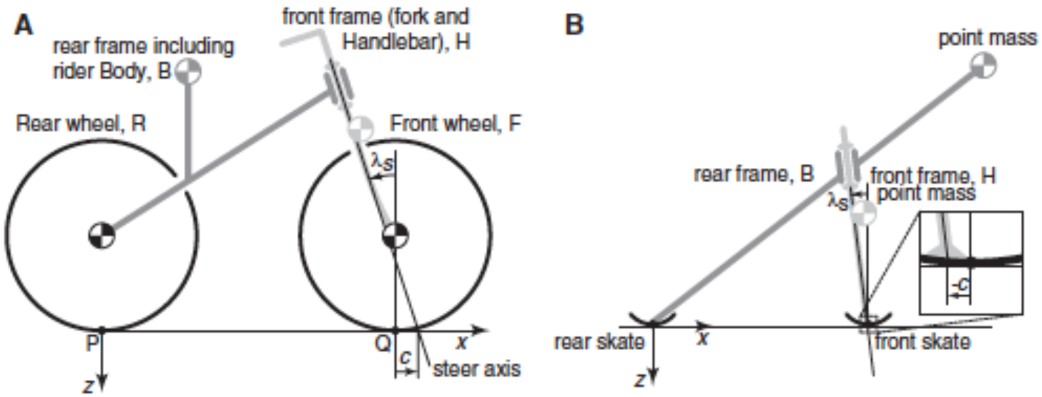

Fig. 1. (**A**) The bicycle model consists of two interconnected frames, B and H, connected to two wheels, R and F. The model has a total of 25 geometry and mass-distribution parameters. Central here are the rotary inertia I_w of the front wheel, the steer axis angle ("rake") λ_s, and the trail distance c (positive if co... forward sp... ase. It is de... ertia and th... no mass m... vent the bi... t shown. Even with negative trail ($c < 0$; inset), this non-gyroscopic bicycle can be self-stable.

Sometimes we make a mistake...
(people misunderstood how bicycle works more than 100 years)

ig. 2. Realization of the model from Fig. 1B. (**A**) The experimental TMS bicycle. (**B**) Front assembly. A counter-rotating wheel cancels the spin angular momentum. The ground contact is slightly ahead of the intersection of the long steer axis line with the ground, showing the small negative trail (movie S3). (**C**) Self-stable experimental TMS bicycle rolling and balancing [photo for (C) by S. Rentmeester/FMAX].

Science
AAAS

A Bicycle Can Be Self-Stable Without Gyroscopic or Caster Effects
J. D. G. Kooijman *et al.*
Science **332**, 339 (2011);
DOI: 10.1126/science.1201959

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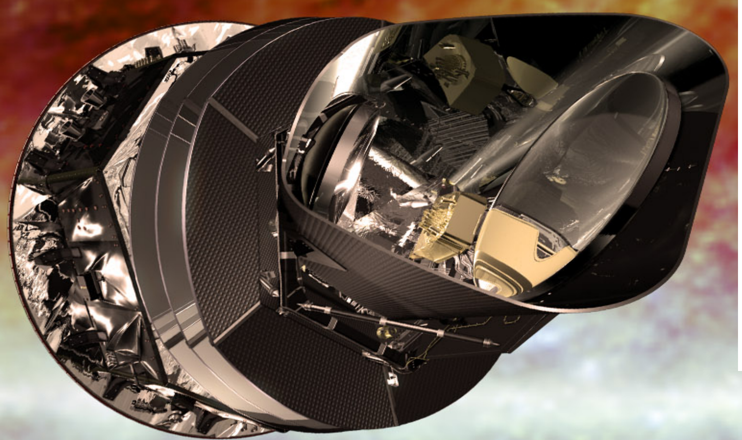

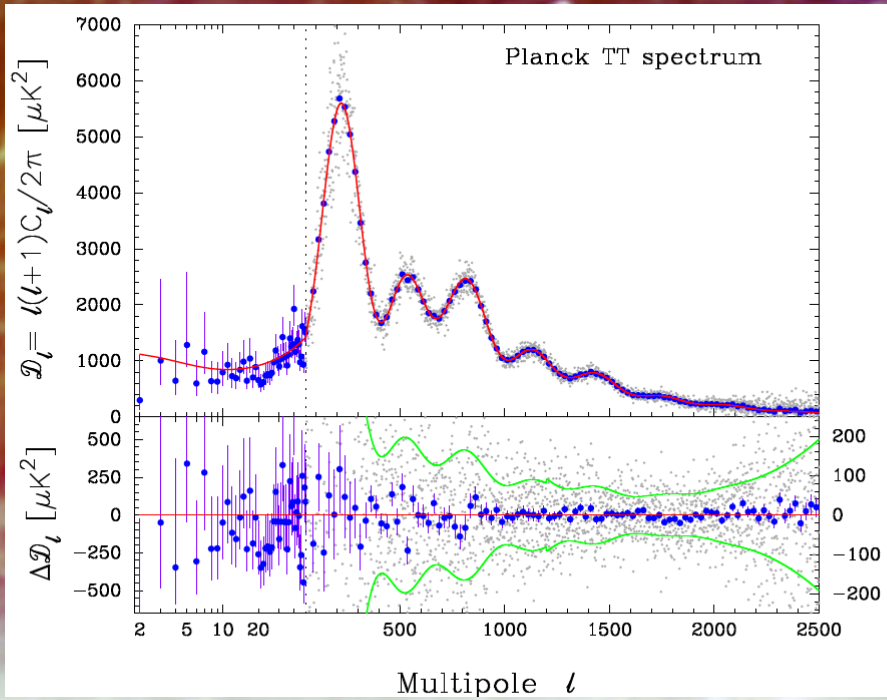

Although we don’t understand so many things, some reason we know so well about the end of the universe

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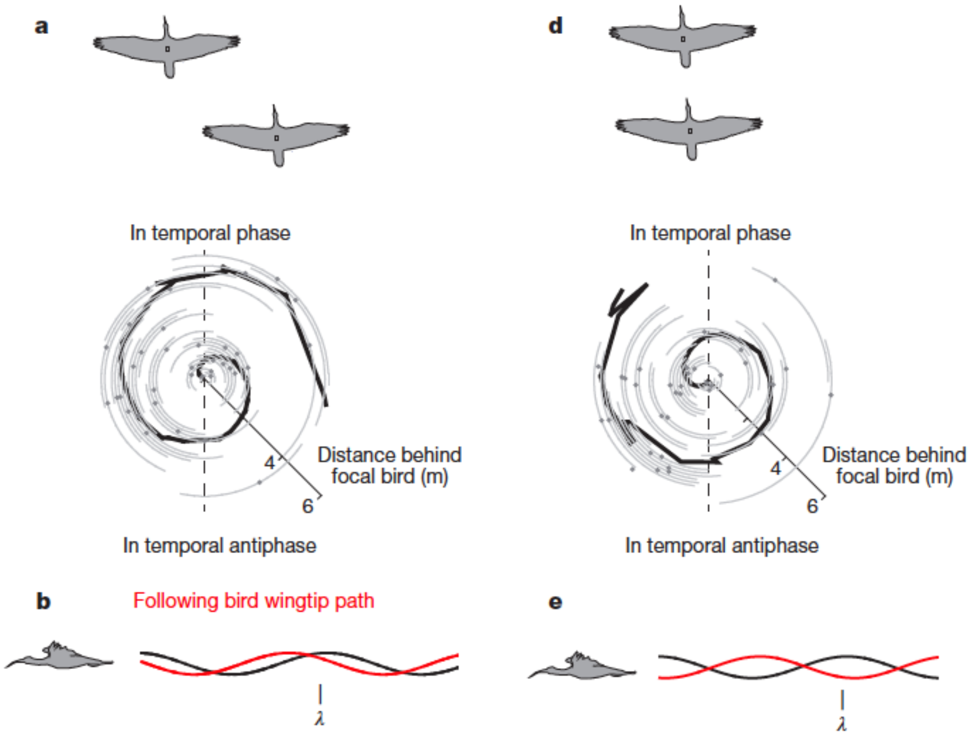

We didn’t know why birds fly with V-formation until few weeks ago!

Upwash exploitation and downwash avoidance by flap phasing in ibis formation flight

Steven J. Portugal[1], Tatjana Y. Hubel[1], Johannes Fritz[2], Stefanie Heese[2], Daniela Trobe[2], Bernhard Voelkl[2,3]†, Stephen Hailes[1,4], Alan M. Wilson[1] & James R. Usherwood[1]

16 JANUARY 2014 | VOL 505 | NATURE | 399

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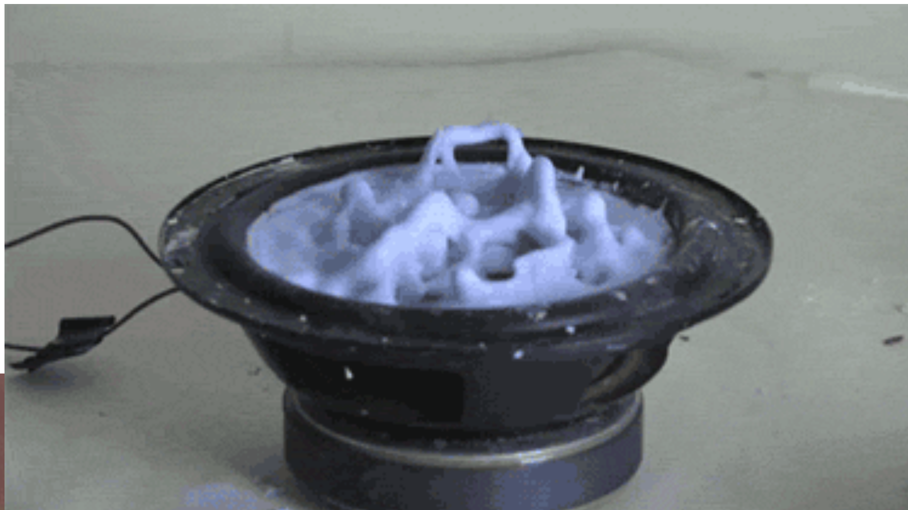

And mysterious things are everywhere (probably in your kitchen, too!)

Non-Newtonian fluid can be made by water and corn starch

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Connection of logic allows to reach higher and higher knowledge

Particle physics

Subject to reach the highest (most non-intuitive) knowledge by adding logics of ladders

Particle physics

Particle physics is the subject to study sub-atomic particles

Elementary particles are responsible to make up
- all matters
- all forces

Laws of elementary particles
- space-time structure
- vacuum structure

Currently, elementary particle physics is described within the framework of the Standard Model

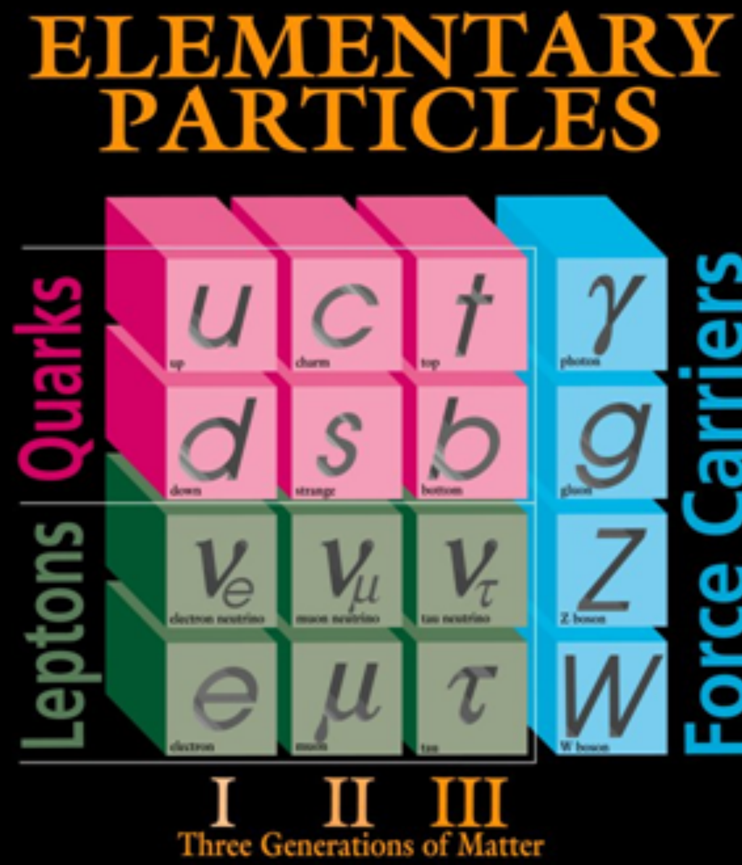
The Standard Model, Elementary Particles of the Universe

- 6 Quarks
  - Up-quarks and Down-quarks make matter

- 6 Leptons
  - 3 Charged Leptons (electron is here)
  - 3 Neutrinos

- 3 Force carries (gauge bosons)
  - Gluon (Strong nuclear force, ~1)
  - Photon (light, ~0.01)
  - Weak bosons (Weak nuclear force, $\sim 10^{-7}$)
  - Gravity is missing from this picture ($\sim 10^{-38}$)

- The "God Particle" Higgs boson
  - Higgs boson gives masses to other particles
  - Discovered in 2012



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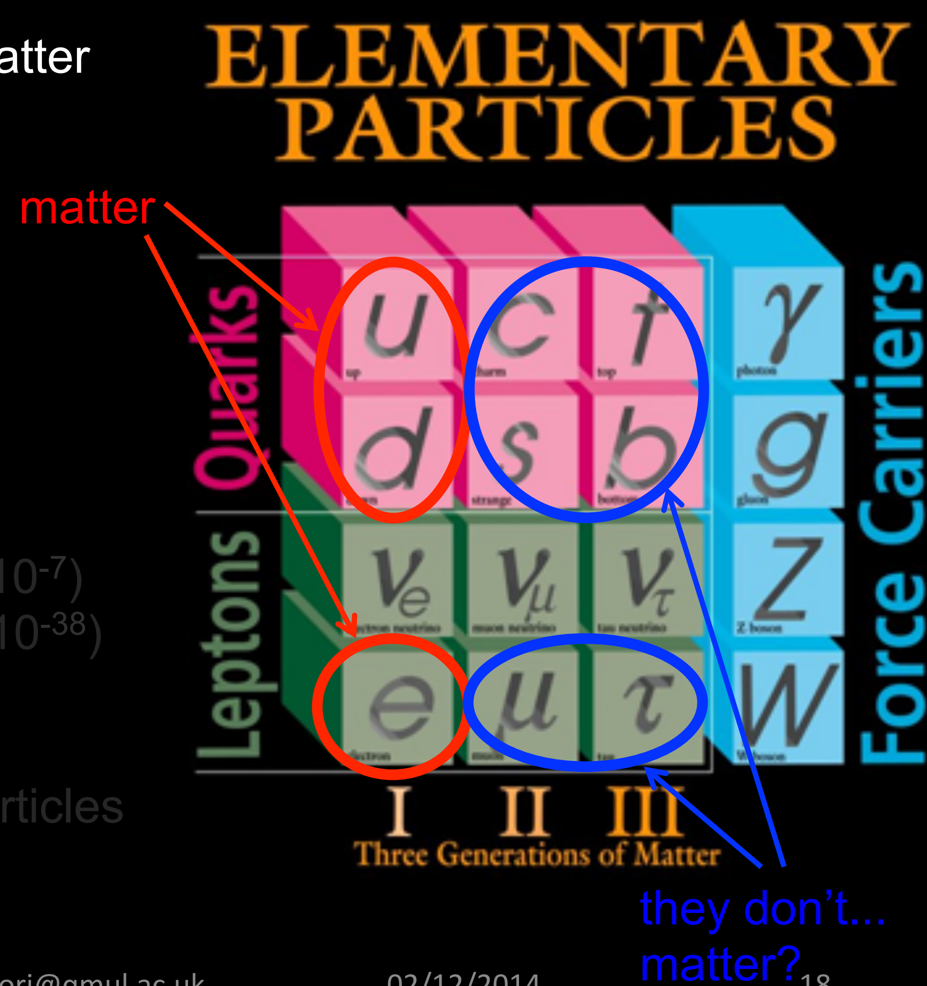

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today's talk

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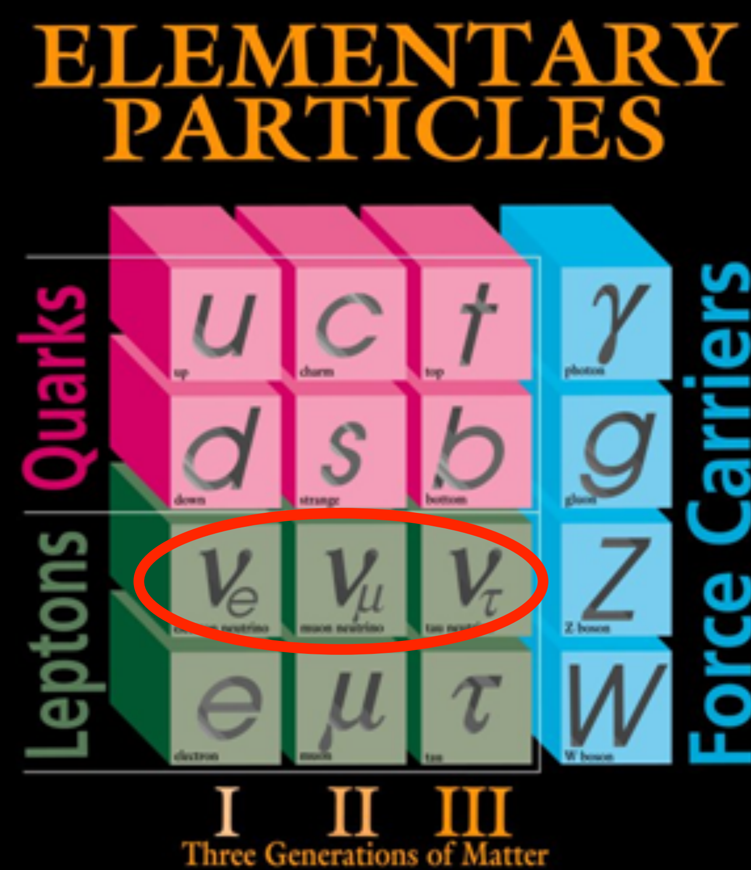

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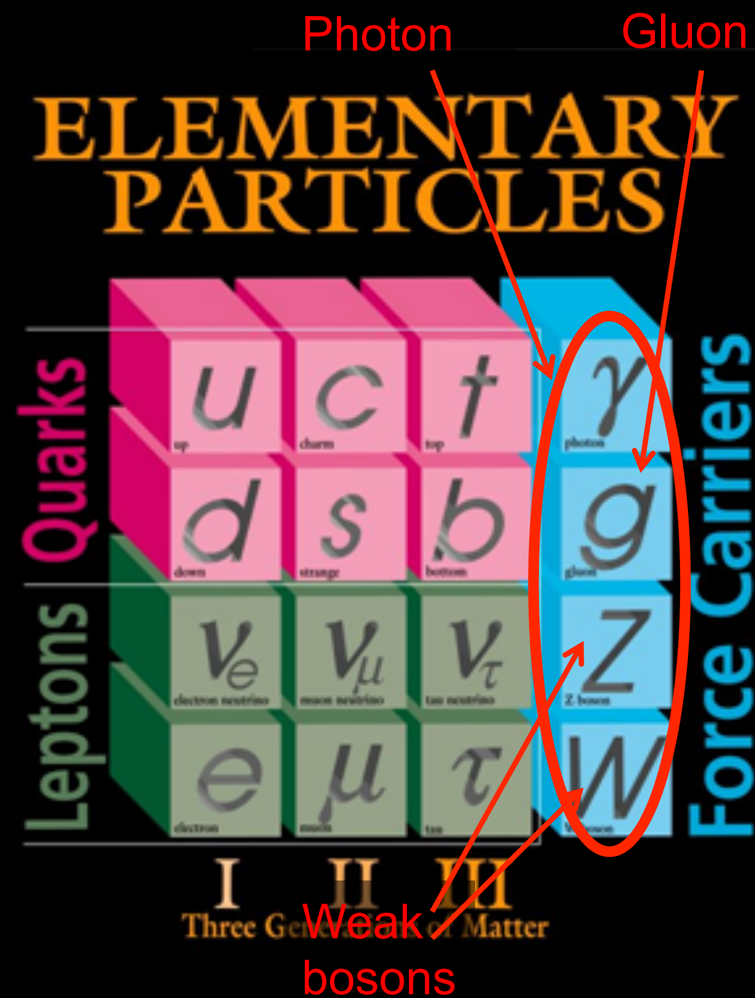

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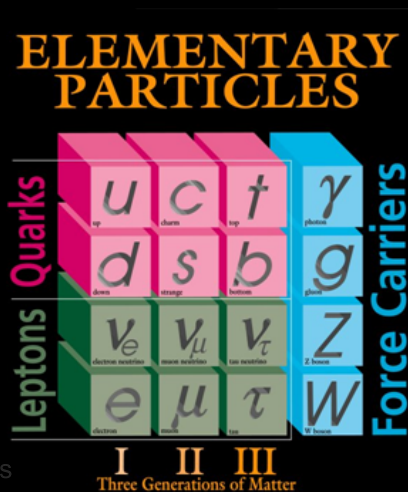

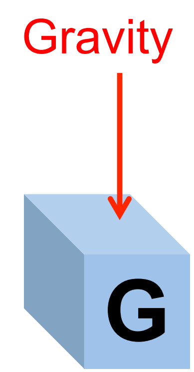

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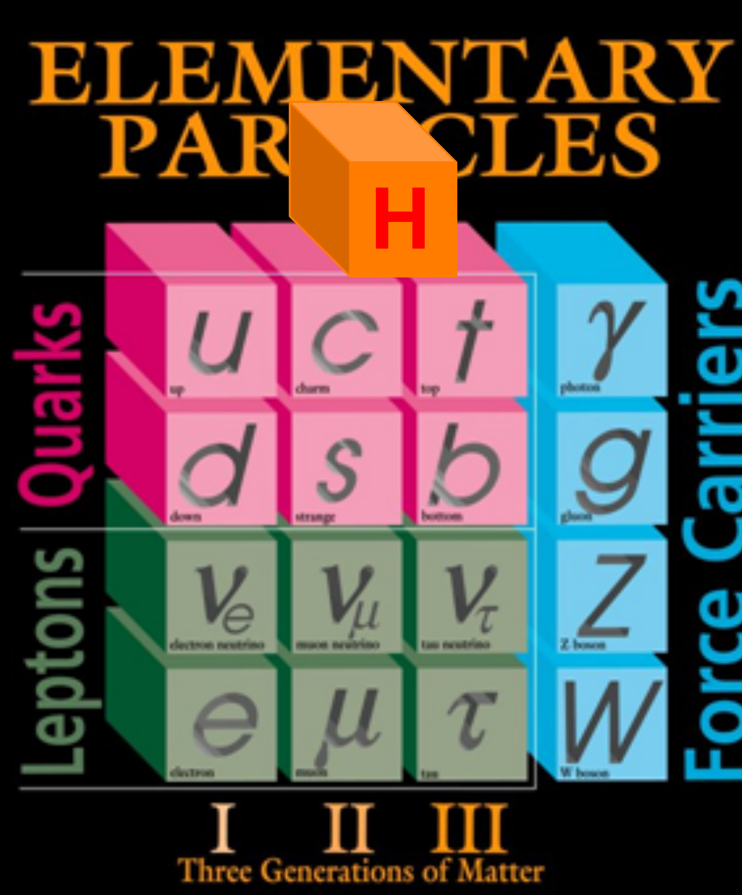


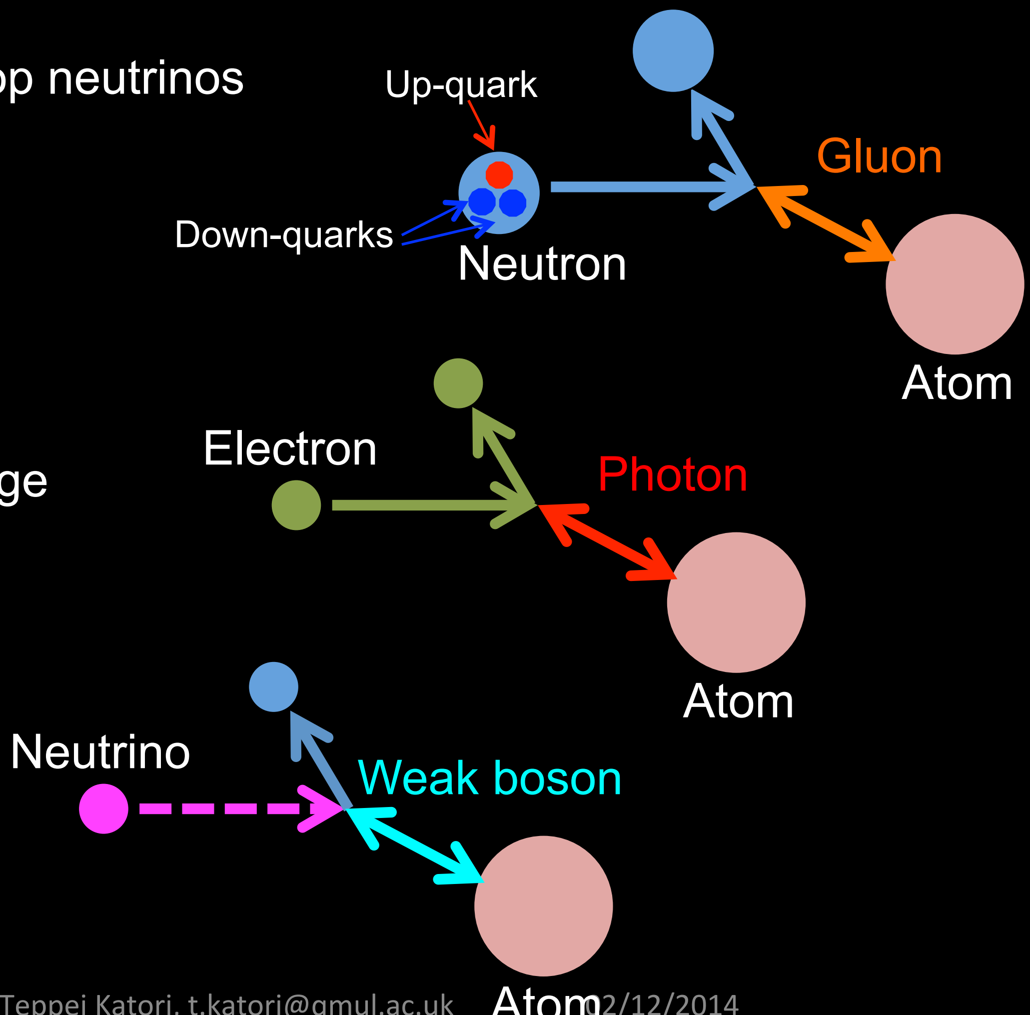
Neutrinos, Ghost particles

3 types of neutrinos
- Extremely difficult to stop neutrinos

- Quarks exchange
  - Gluons, or
  - Photons, or
  - Weak bosons

- Charged leptons exchange
  - Photons, or
  - Weak bosons

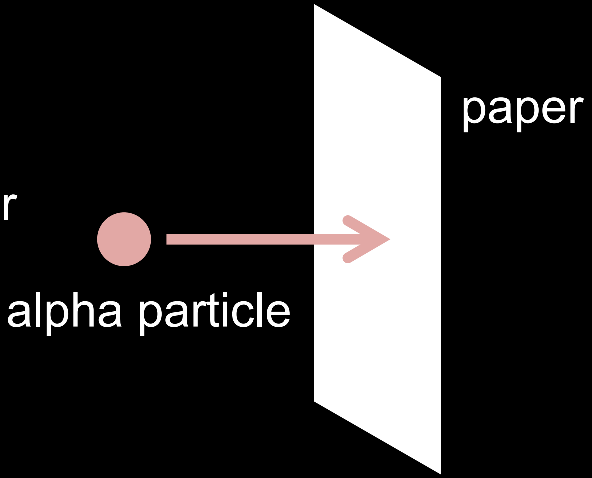
- Neutrinos exchange
  - Weak bosons



Neutrinos, Ghost particles

3 types of neutrinos
- Extremely difficult to stop neutrinos

Example: how to stop particles?
- Alpha particle (nuclei of Helium) → sheet of paper
- Beta particle (electron) → sheet of copper
- Gamma particle (photon) → chunk of lead



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Example: how to stop particles?
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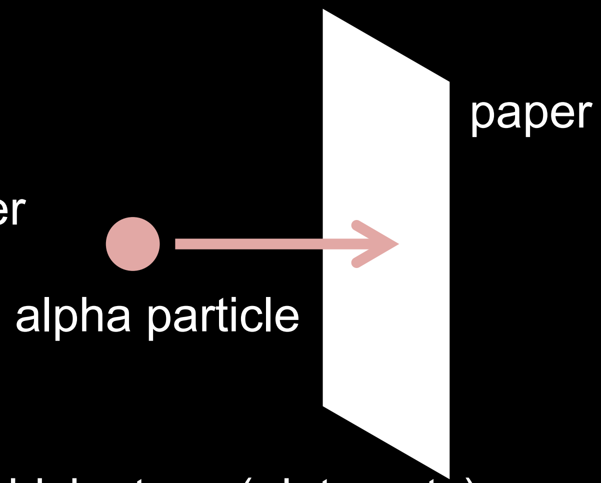
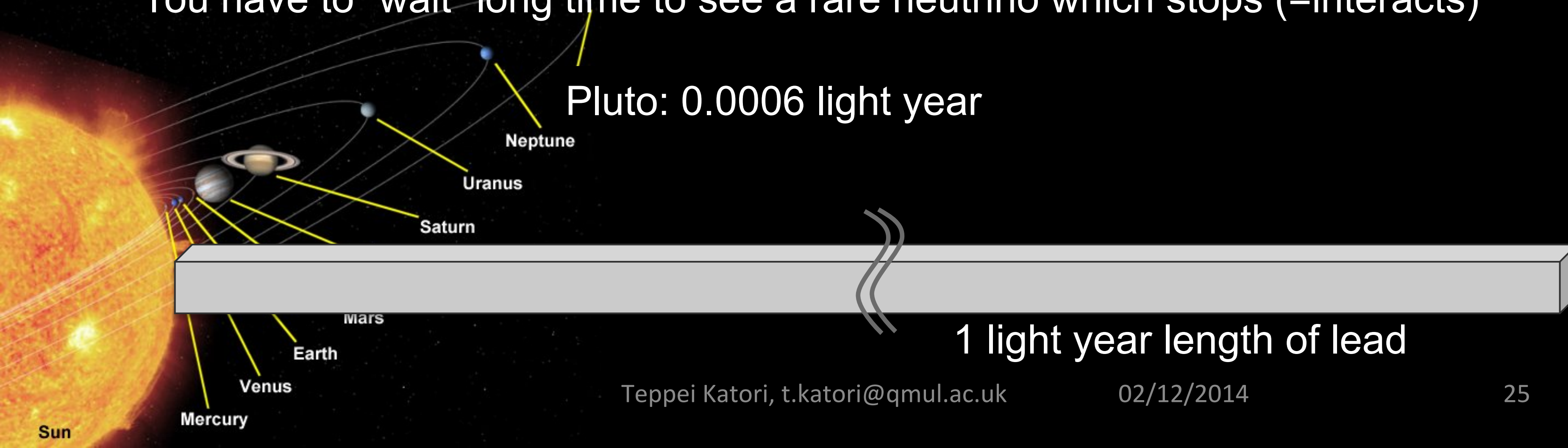
- Neutrino → 1 light year thickness of lead



You have to "wait" long time to see a rare neutrino which stops (=interacts)



Neutrinos, Ghost particles

3 types of neutrinos
- Extremely difficult to stop neutrinos

Neutrinos are everywhere, but they penetrate without leaving any traces.

- 50,000 muon neutrinos (made by collisions of cosmic rays and air) penetrate your body every second.

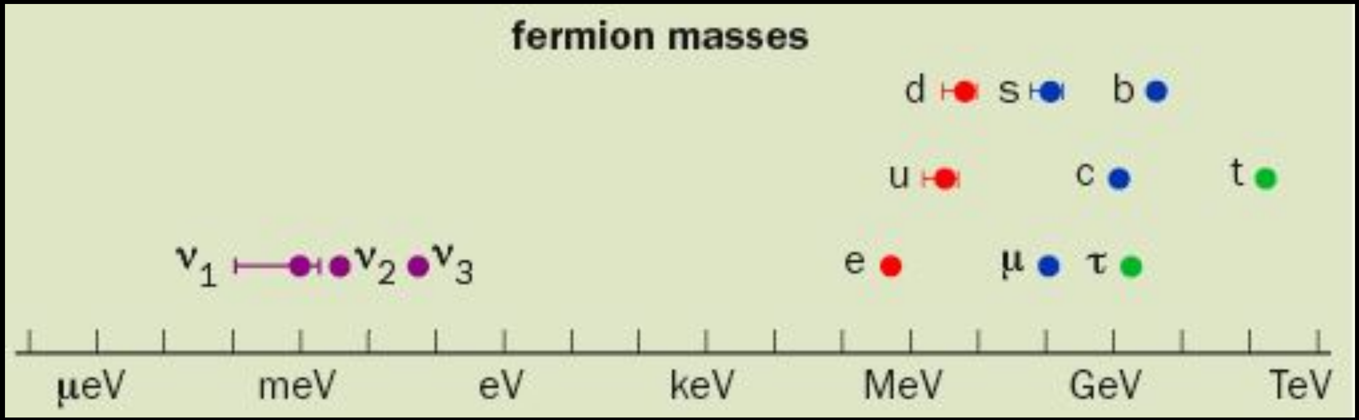
- 60 billion electron neutrinos from the Sun pass through every 1cm^2 of the Earth every second. However you have only a 25% chance for a neutrino to hit your body in your lifetime.

- Every place in the Universe has ~330 neutrinos/cm^3 made by Big Bang. Neutrinos are the second most abundant particle in the Universe (photons~410/cm^3).

Neutrinos, Ghost particles

3 types of neutrinos
- Extremely difficult to stop neutrinos
- Extremely small mass

Tiny mass of weakly interacting neutrino cannot be measured by traditional methods, it can be measured only by neutrino oscillation, with a help of quantum mechanics



Neutrino Oscillations

Neutrinos obey quantum mechanics
- State of neutrinos are not well-defined in space and time (Schrödinger's cat)
- Type of neutrino is not conserved with time
- If so, neutrinos have masses

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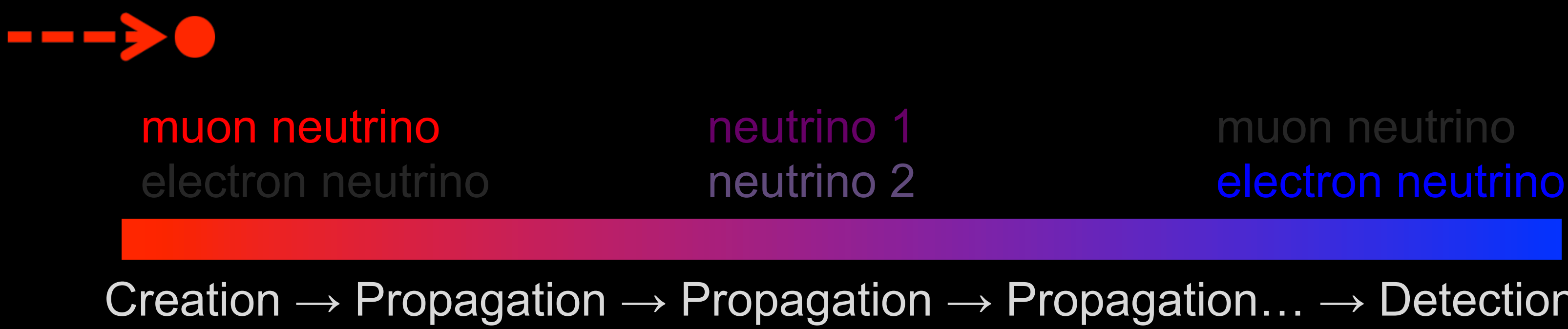

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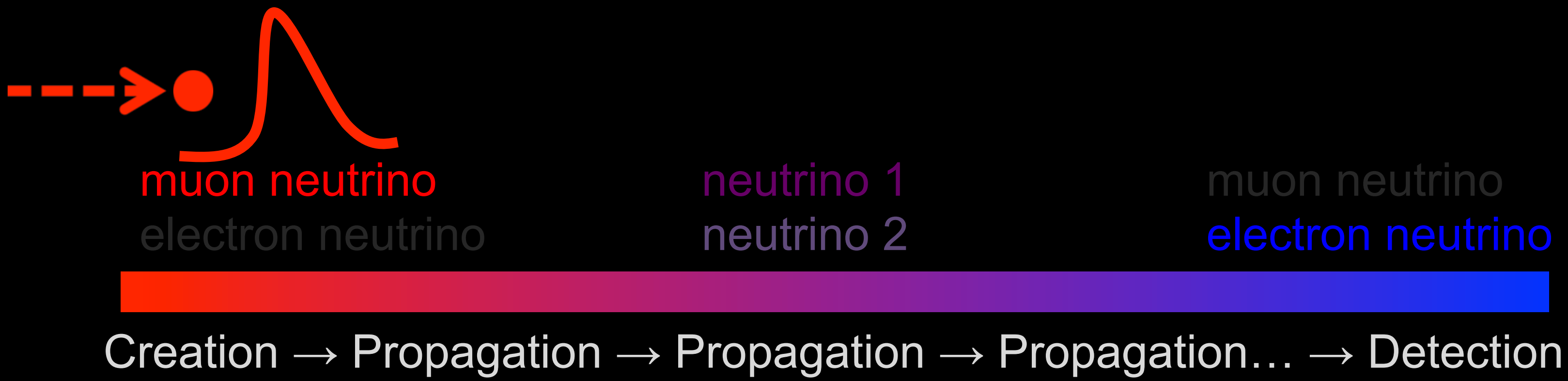

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Creation → Propagation → Propagation → Propagation… → Detection

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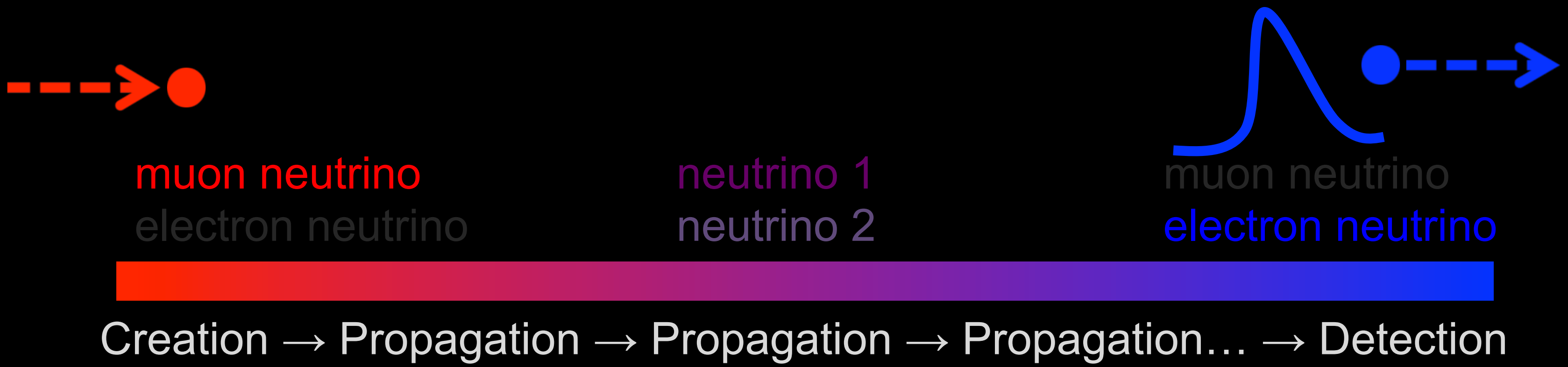

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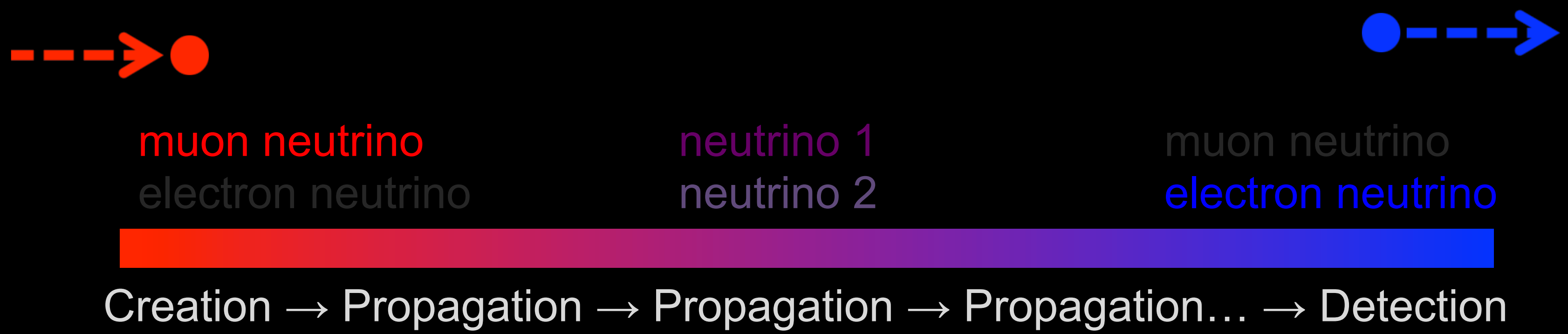

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muon neutrino
electron neutrino

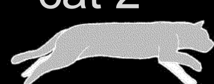
neutrino 1
neutrino 2

muon neutrino
electron neutrino

Creation → Propagation → Propagation → Propagation… → Detection

cat 1

cat 2



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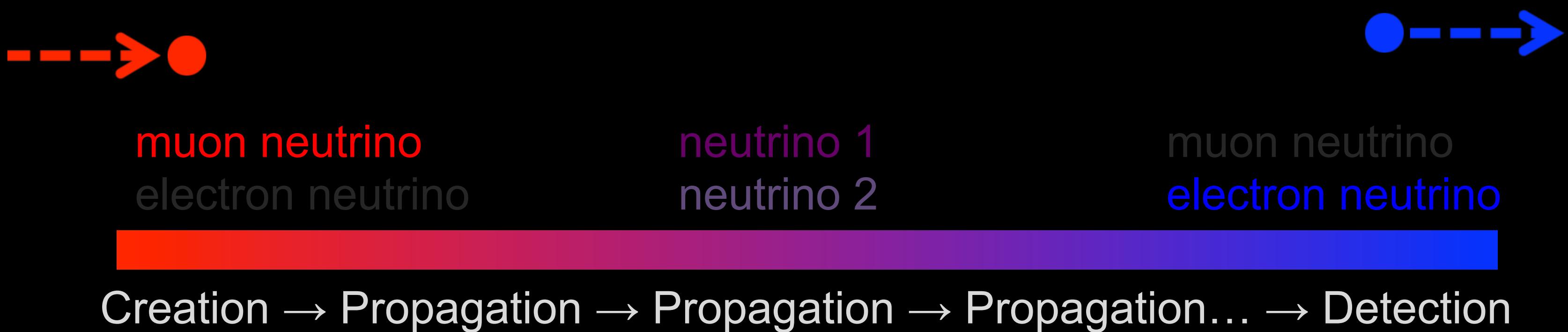
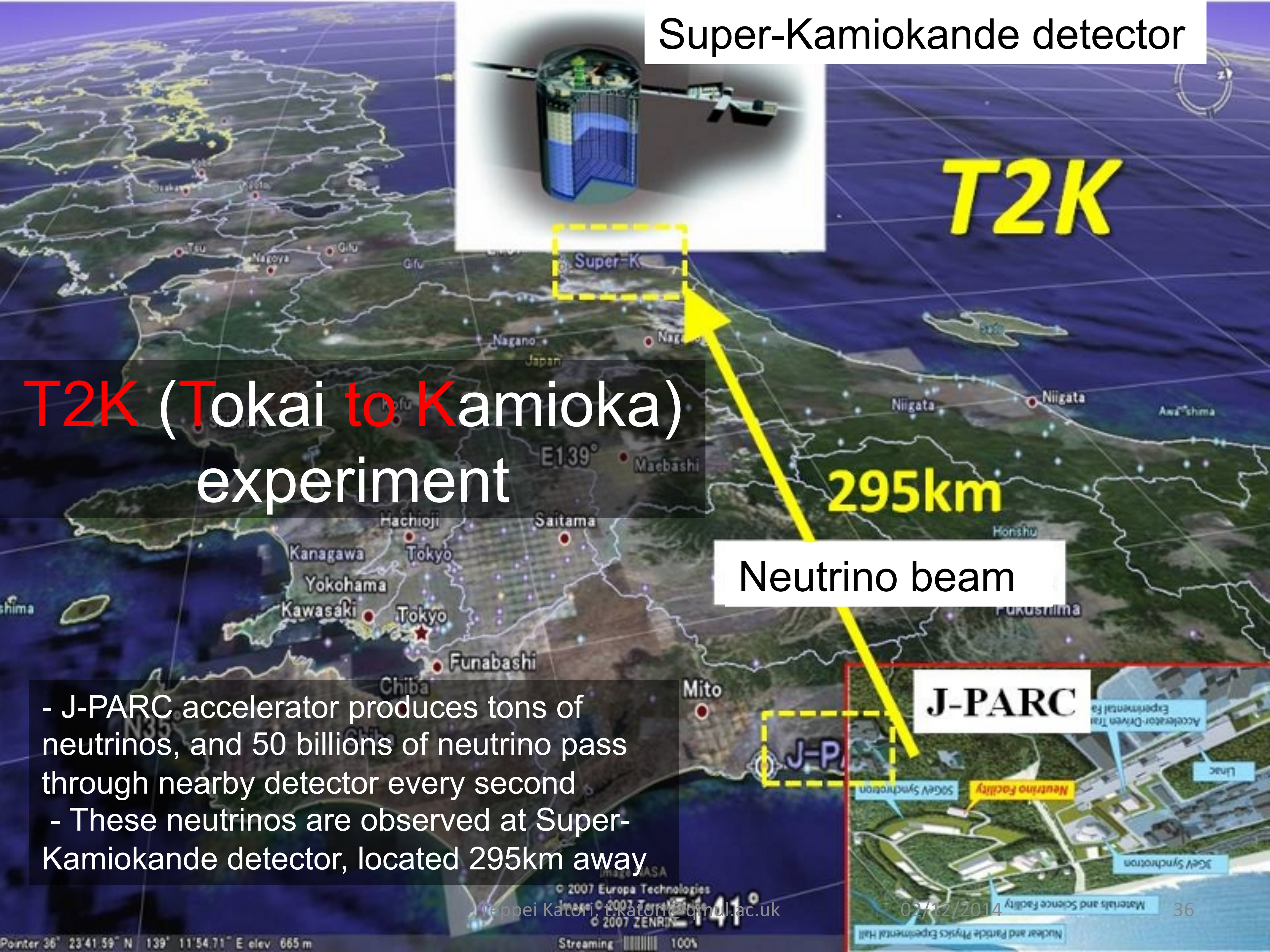
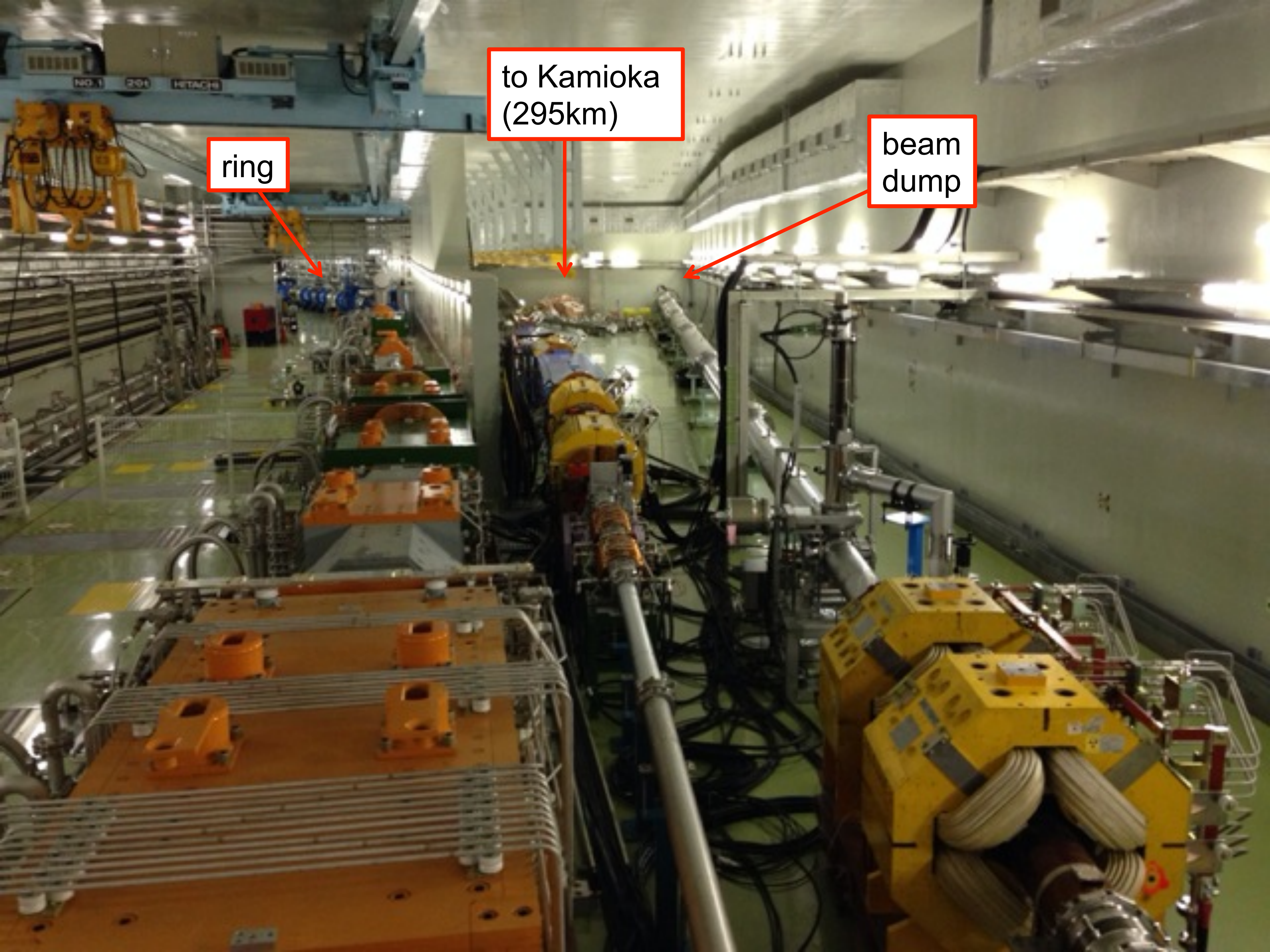


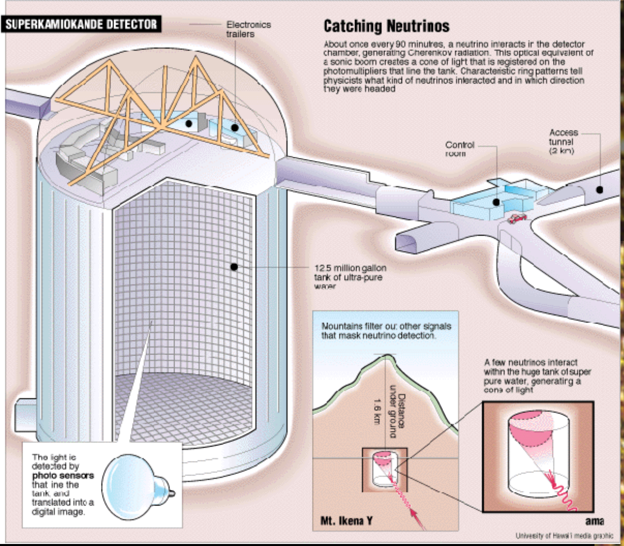
T2K (Tokai to Kamioka) experiment

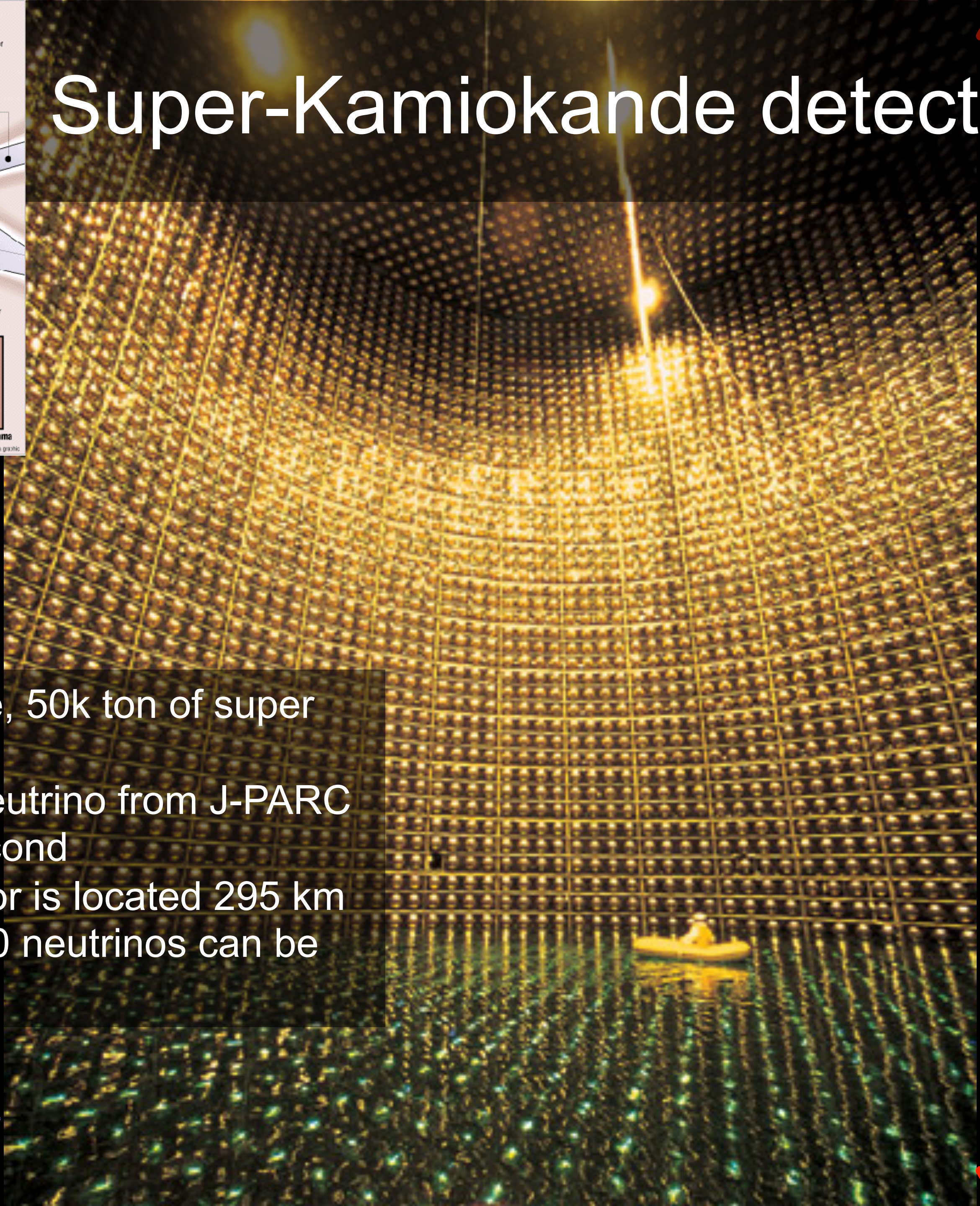
- J-PARC accelerator produces tons of neutrinos, and 50 billions of neutrino pass through nearby detector every second
- These neutrinos are observed at Super-Kamiokande detector, located 295km away




to Kamioka (295km)
ring
beam dump
NO.1
20t
HITACHI

Super-Kamiokande detector





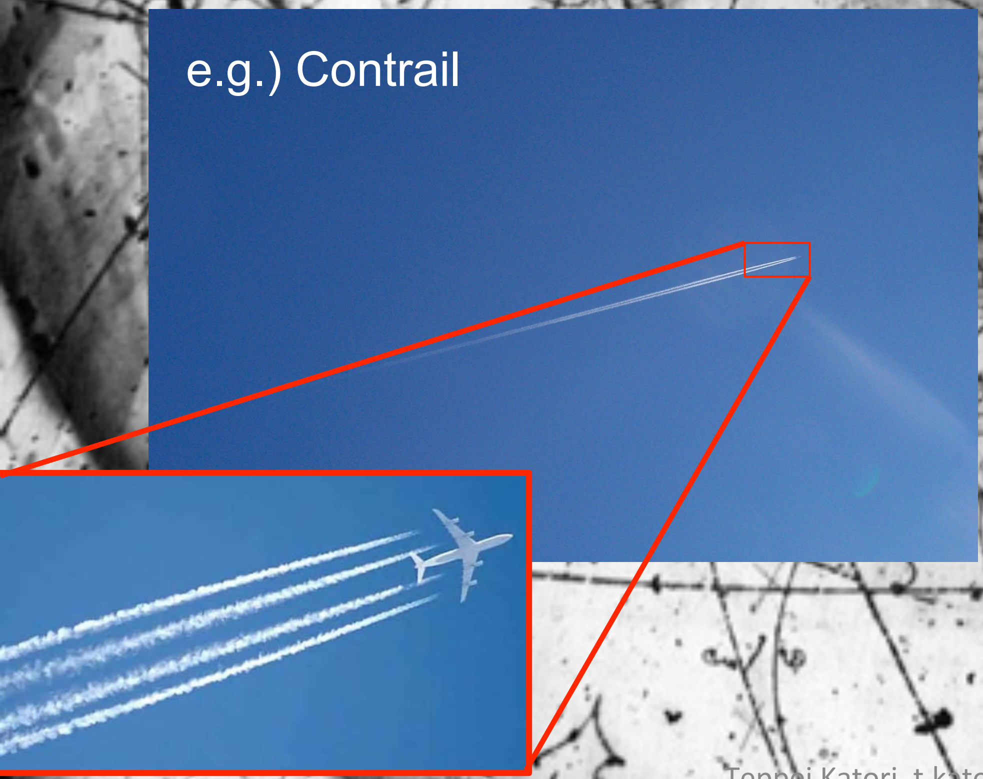
40m

- 40m height, 40m wide, 50k ton of super pure water
- Roughly 25 million neutrino from J-PARC pass through every second (remember, this detector is located 295 km away!), but less than 10 neutrinos can be seen in a day...

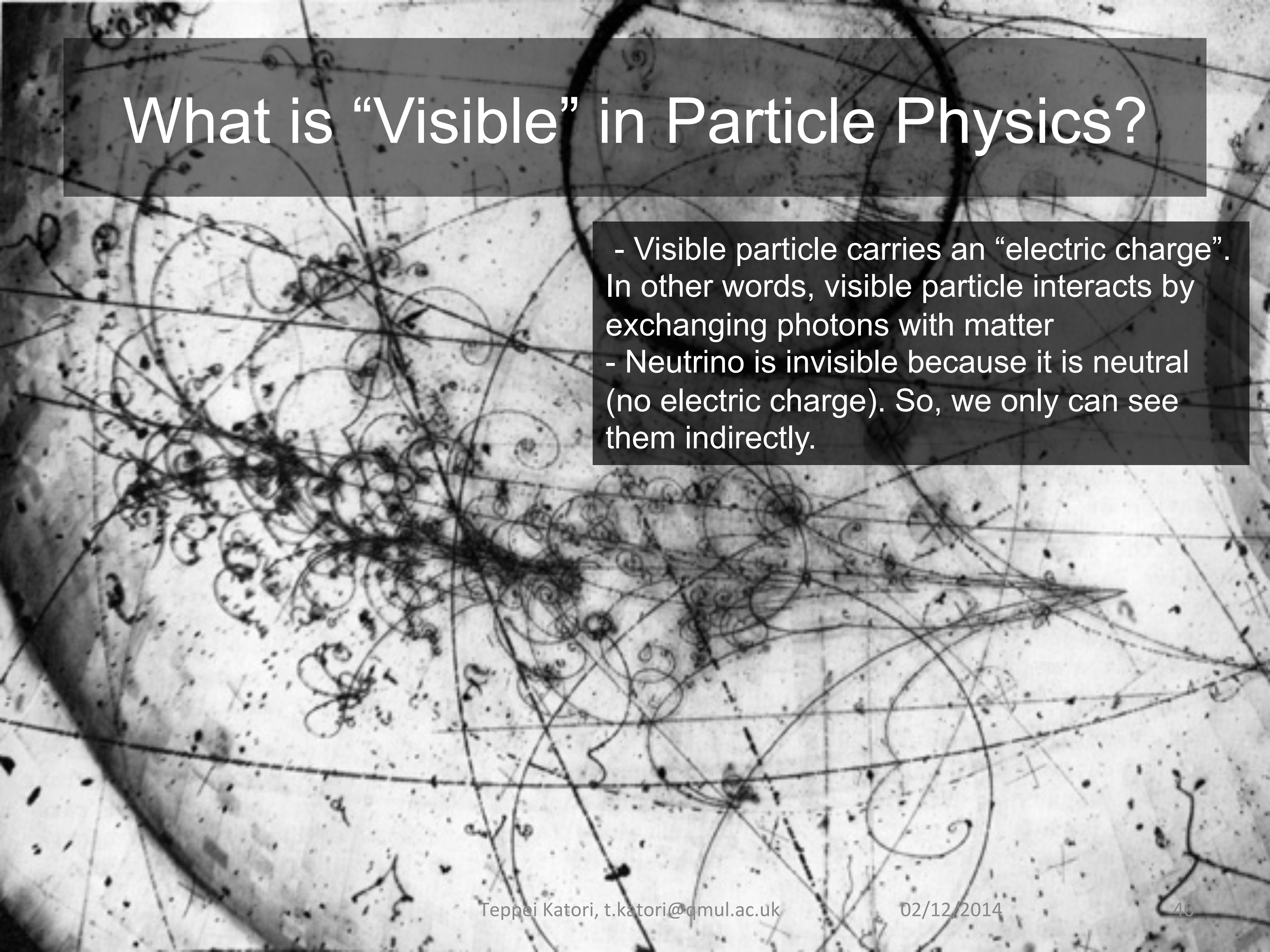
Queen Mary
University of London

What is “Visible” in Particle Physics?

Bubble Chamber detector
- Particles with an electric charge leave “tracks” in the detector by forming little bubbles, and we can take photos of them.



What is "Visible" in Particle Physics?



- Visible particle carries an "electric charge". In other words, visible particle interacts by exchanging photons with matter
- Neutrino is invisible because it is neutral (no electric charge). So, we only can see them indirectly.

What is "Visible" in Particle Physics?

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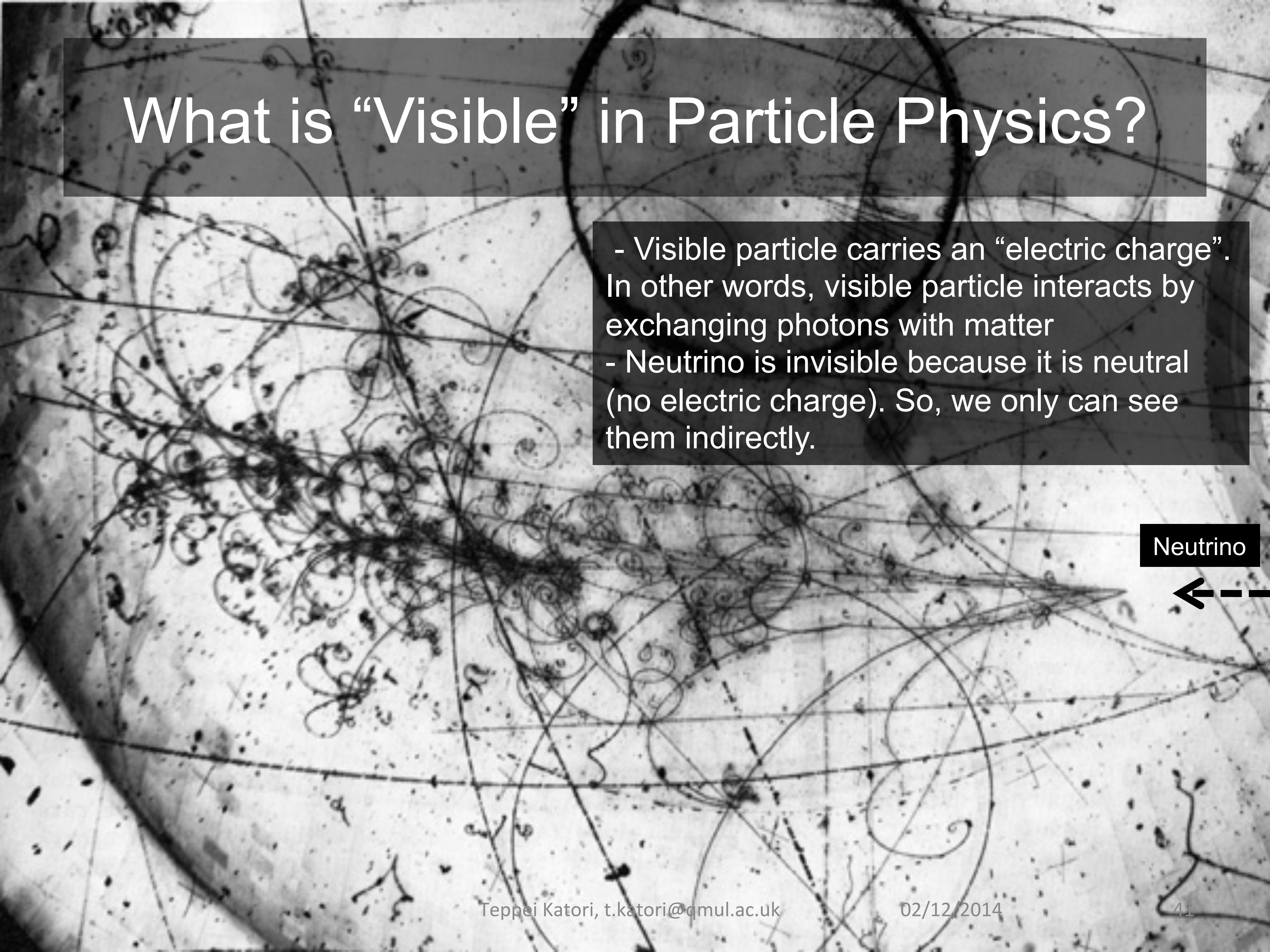
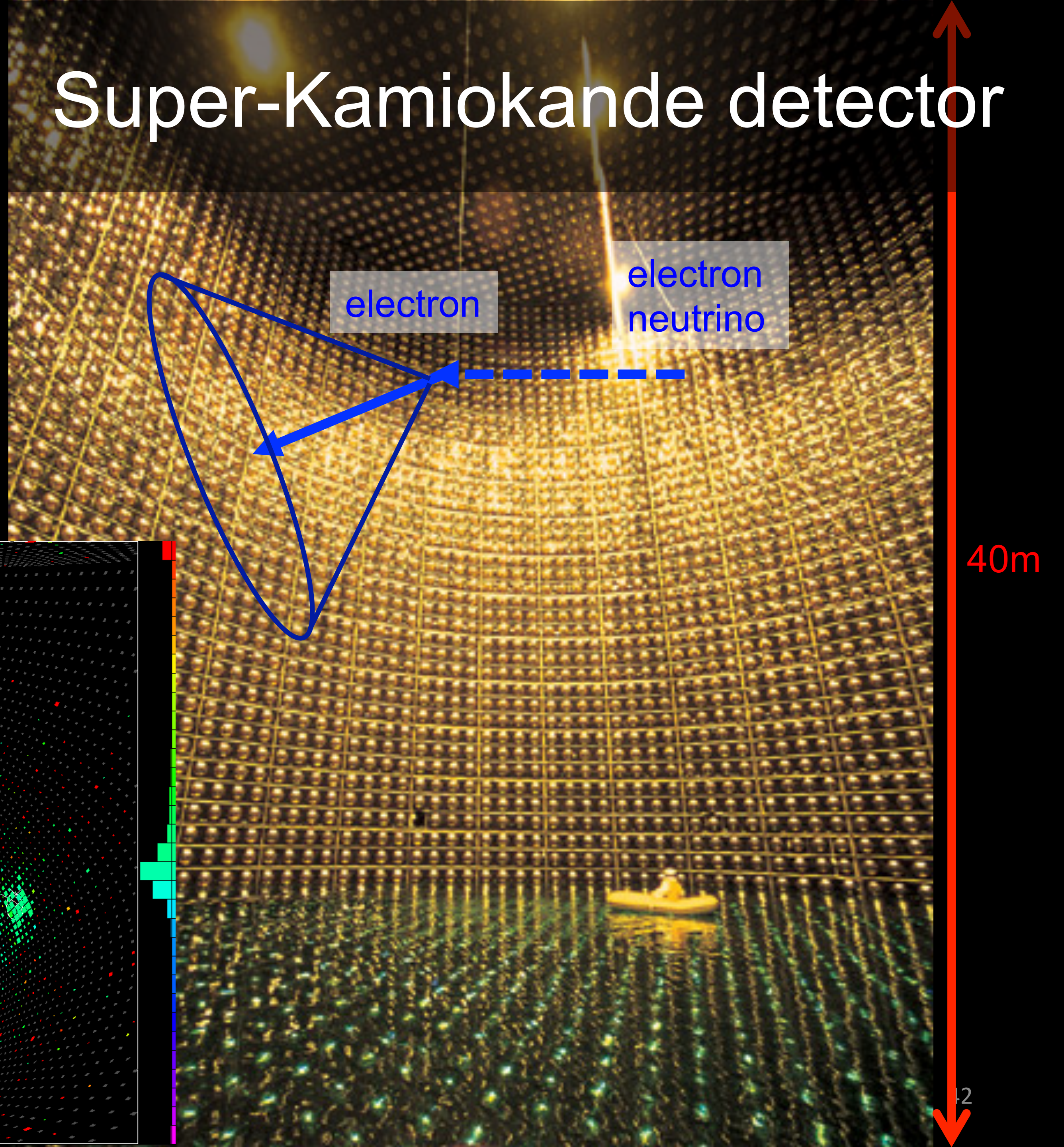
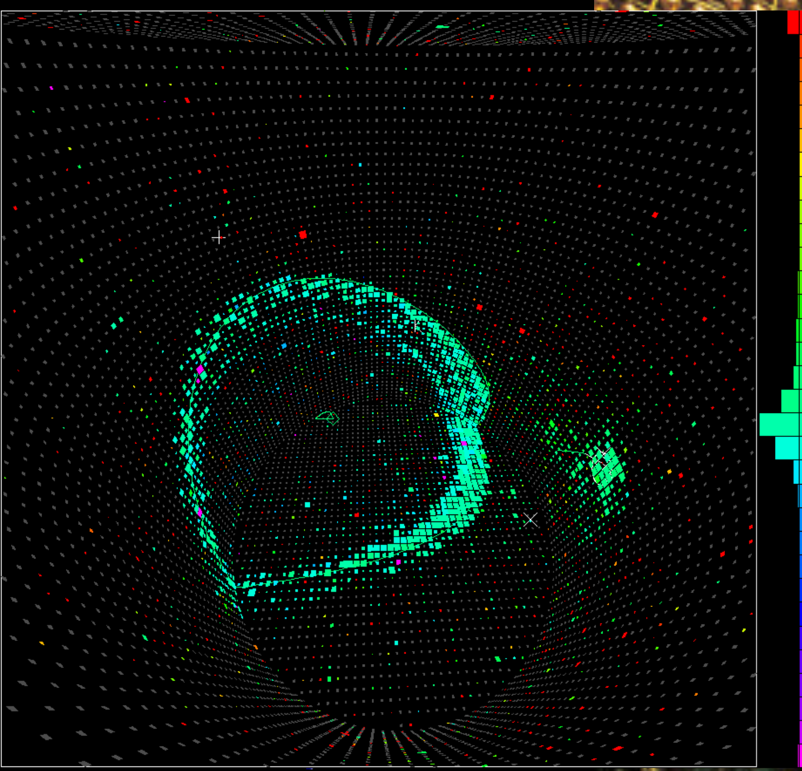


Super-Kamiokande detector

Super-Kamiokande observes Cherenkov radiation of charged particles from the neutrino interaction with water molecule

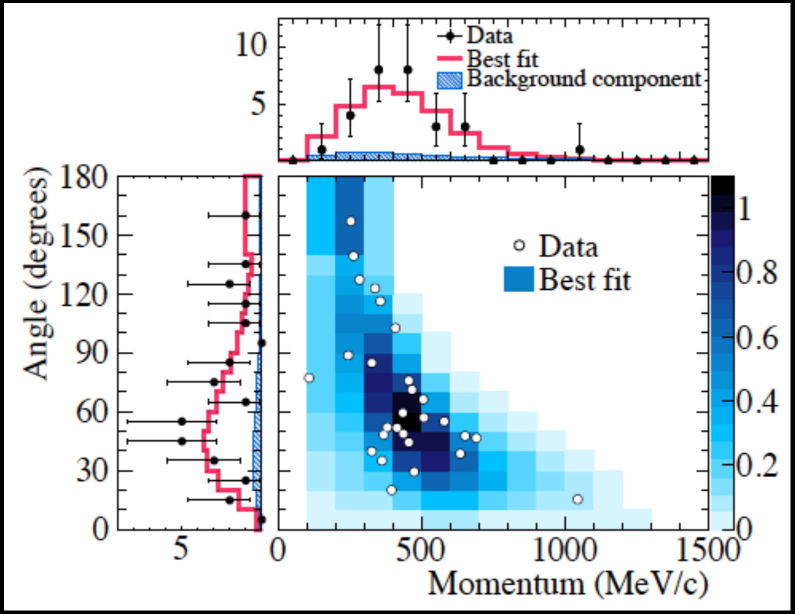


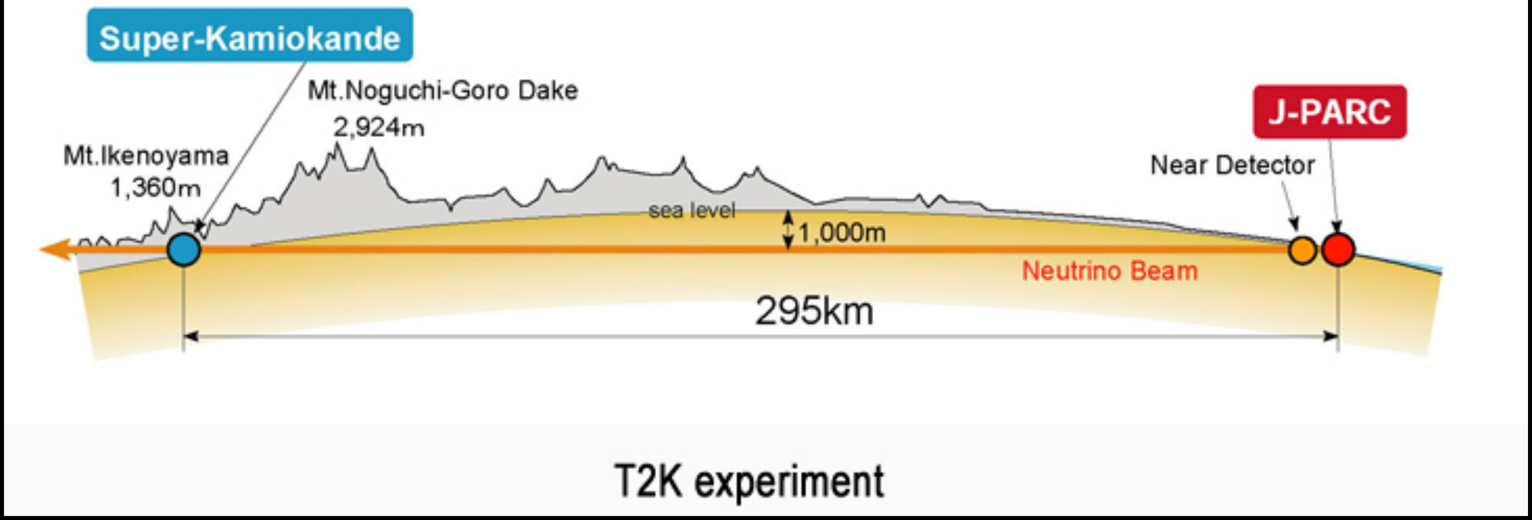


Neutrino Oscillations

T2K experiment measured 23 electron neutrinos from muon neutrino beam. This is the evidence of muon neutrinos oscillate to electron neutrino neutrinos!

$$
\begin{aligned}
P_{\nu_\mu \to \nu_e} = {} & \frac{1}{(A-1)^2}\sin^2 2\theta_{13}\sin^2\theta_{23}\sin^2[(A-1)\Delta] \\
& -(+)\frac{\alpha}{A(1-A)}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13} \\
& \times \sin\delta_{CP}\sin\Delta\sin A\Delta\sin[(1-A)\Delta] + \frac{\alpha}{A(1-A)} \\
& \times \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13} \\
& \times \cos\delta_{CP}\cos\Delta\sin A\Delta\sin[(1-A)\Delta] \\
& + \frac{\alpha^2}{A^2}\cos^2\theta_{23}\sin^2 2\theta_{12}\sin^2 A\Delta. \qquad (2)
\end{aligned}
$$

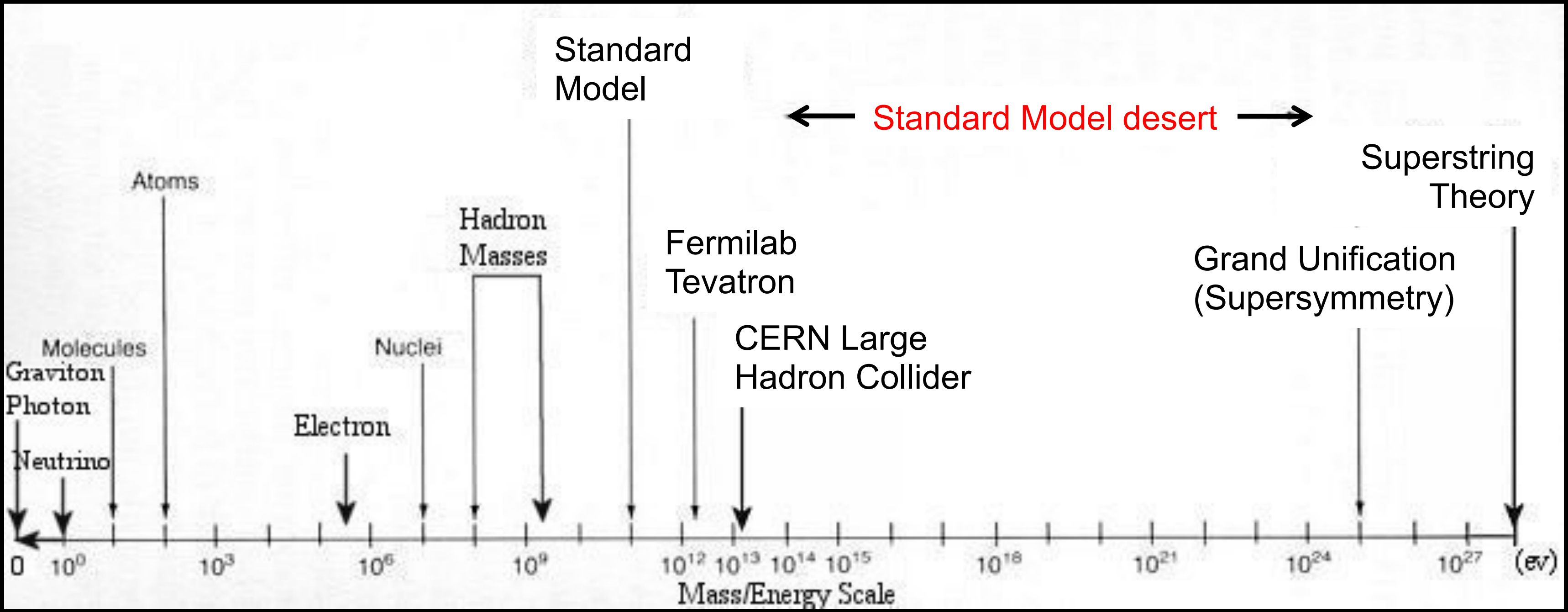




Neutrinos, beyond the Standard Model?

- Neutrino masses are not predicted by the Standard Model
- Extremely small neutrino masses are related with Grand Unification Theory?

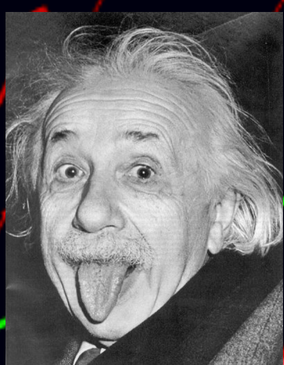
$$M(\text{neutrino}) \sim \frac{(\text{Energy scale of Standard Model})^2}{(\text{Energy scale of Grand unification})}$$

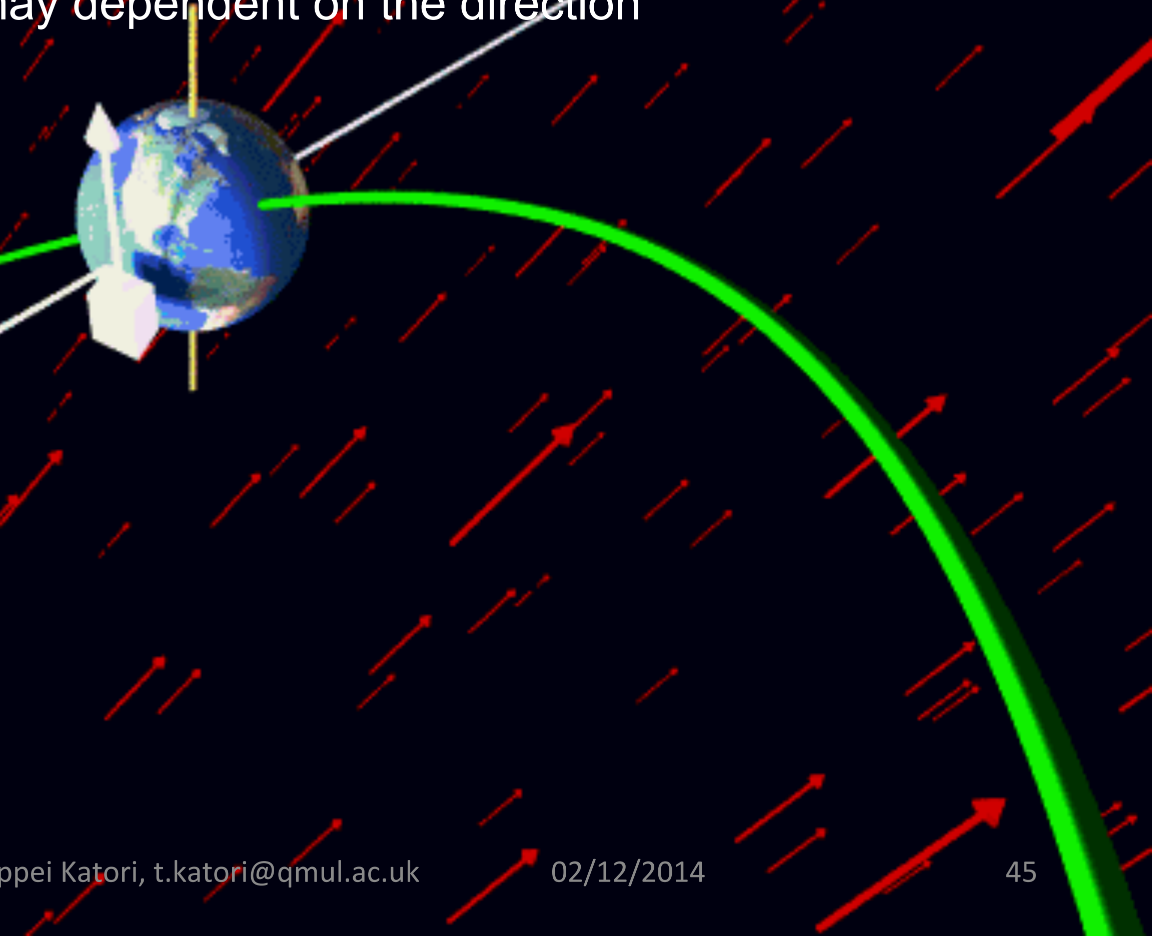


Bluhm. Kostelecky. Lane. Russell PRL 2002

Neutrinos, beyond the Standard Model?

Neutrino oscillation is useful to test space-time structure (Lorentz symmetry)
- Violation of Lorentz symmetry is natural in Ultra high energy theories
- If so, neutrino oscillation may dependent on the direction
- New structure of vacuum?
- Einstein may be wrong?





End

- Neutrinos are elementary particles of the Universe

- Neutrinos are ghostly particles, penetrating everything

- Neutrinos change species when they propagate. This is called neutrino oscillations

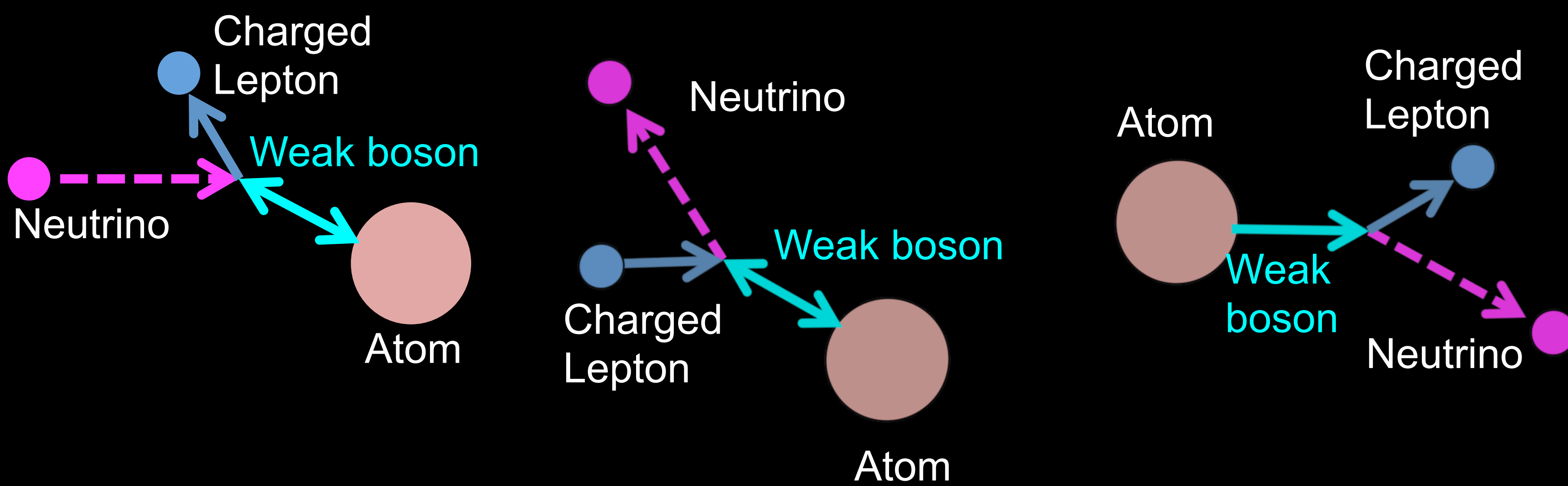
- Extremely small neutrino mass may be a signal of ultra high energy physics, such as Grand Unification Theory and Supersymmetry

Back up

Neutrinos, Ghost particles

- Neutrinos only exchange weak bosons
  - 3 types of neutrinos

Electron neutrino: creates electron, or created by electron, or created with electron
Muon neutrino: creates muon, or created by muon, or created with muon
Tau neutrino: creates tauon, or created by tauon, or created with tauon



Neutrino applications

EUROPHYSICS LETTERS

Europhys. Lett., **60** (1), pp. 34–39 (2002)

Could one find petroleum using neutrino oscillations in matter?

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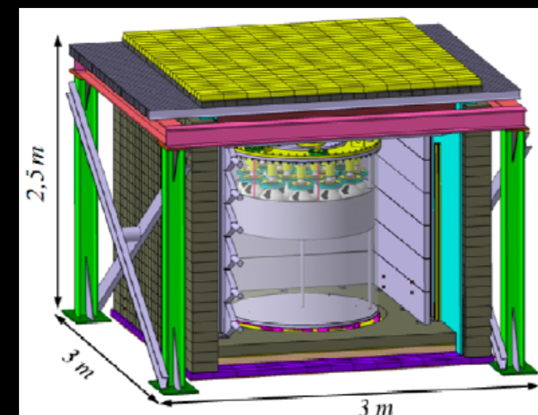

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DEMONSTRATION OF COMMUNICATION USING NEUTRINOS

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Submarine neutrino communication

Patrick Huber

Department of Physics, Virginia Tech, Blacksburg, VA 24061, USA

Letters B 671 (2009) 15–19

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Galactic neutrino communication

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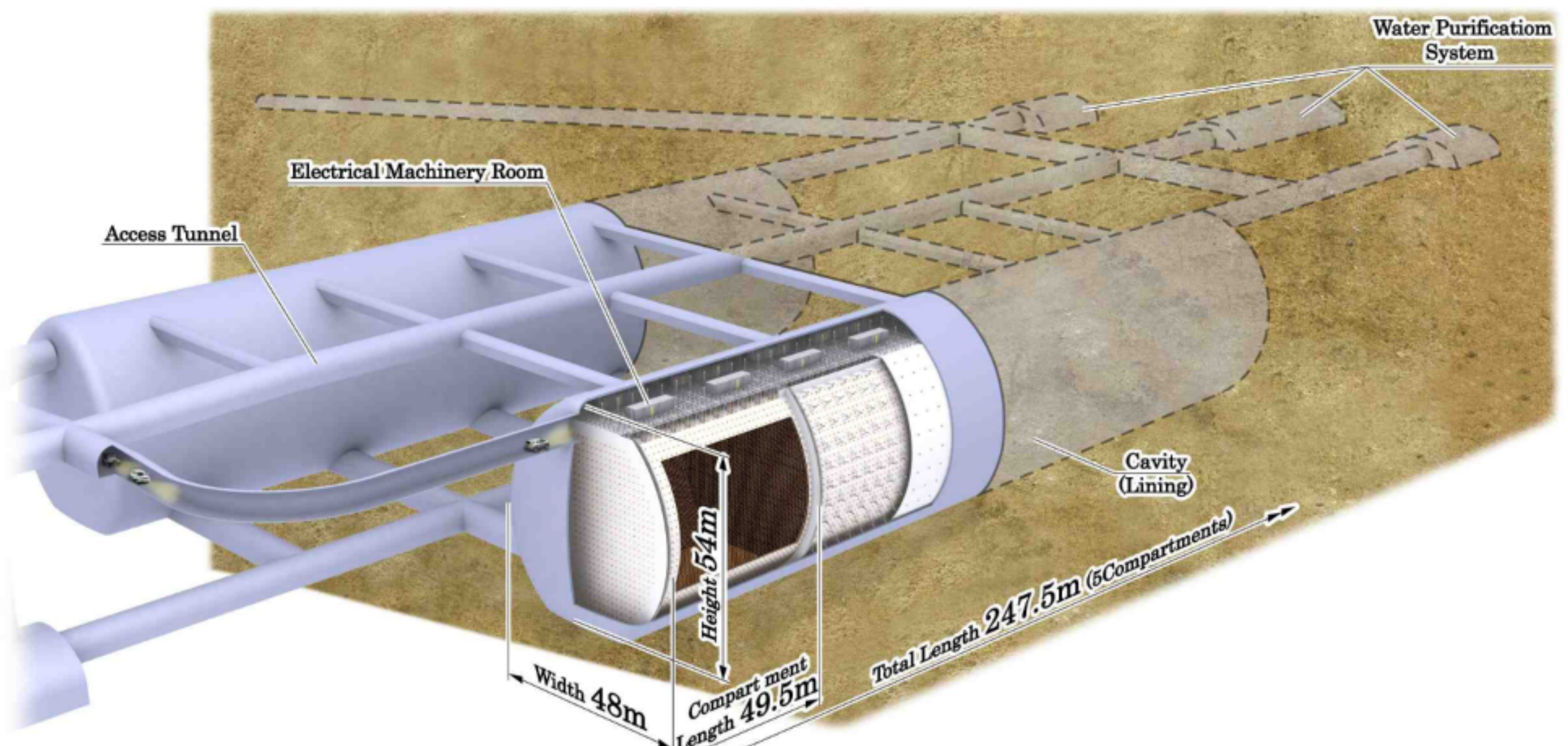
[b] *Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA*

Hyper-Kamiokande detector

- 1 megaton water tank
- sensitive to small type of neutrino oscillations
- detect neutirnos from the Sun, atmosphere, supernova, etc



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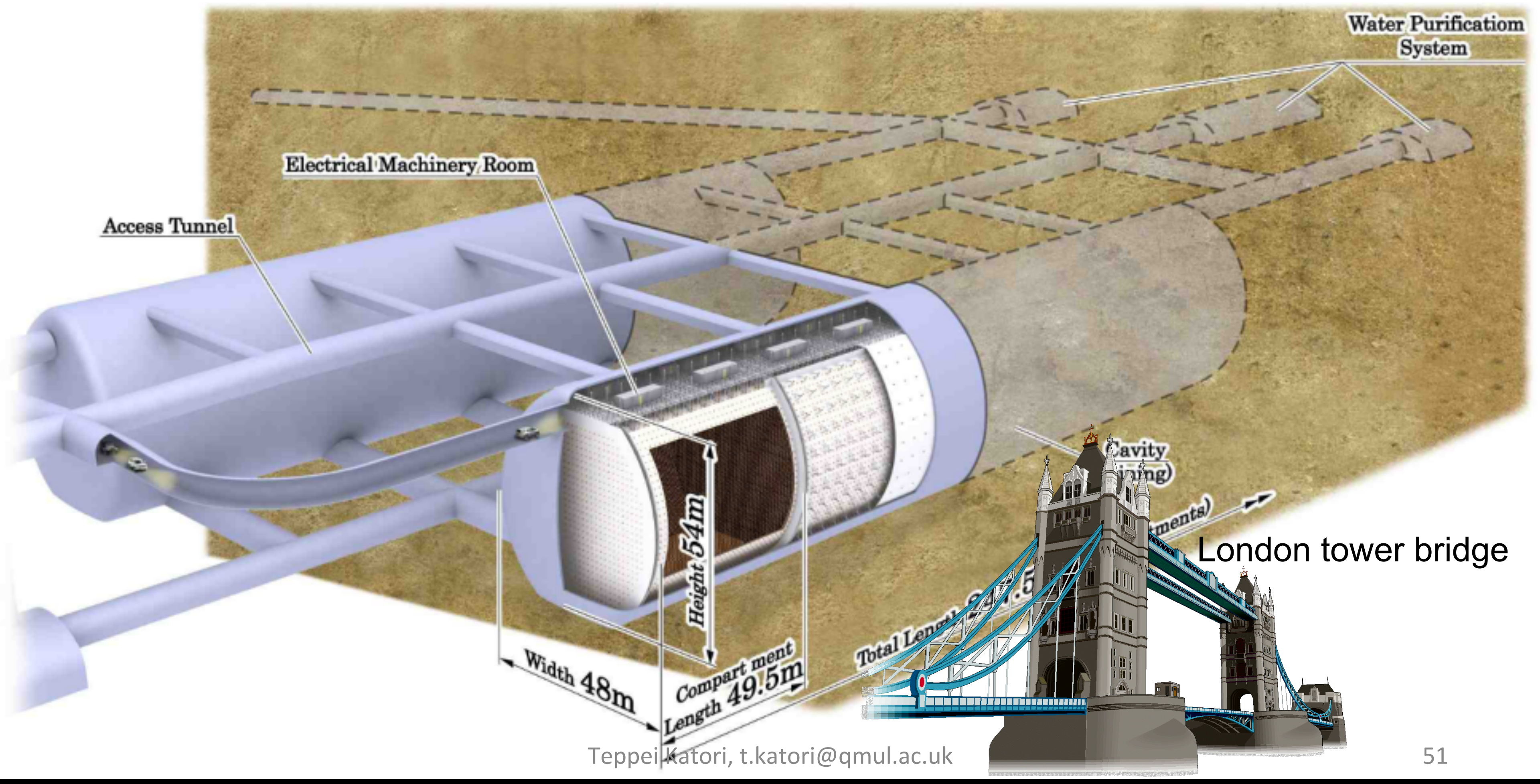

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