2. The Birth of Matter -Elementary Particles, Atoms, and the Universe-

- Lecture 1 How do we conceive of the physical world? –structural hierarchy of matter-
- Lecture 2 The motion of the physical world. –physical law-
- Lecture 3 Space-time –the "stage" of matter - Space-time and matter are united in motion to determine the structure of the world

Lecture 4 The creation and evolution of the universe –for a comprehensive understanding of nature-

The Motion of the Physical World
–Physical laws-

- Classical mechanics and its determinism.
- The two pillars of modern physics—quantum theory and relativity. We will focus on quantum theory in this lecture.
- The unification of fundamental laws.
- Why are physical laws so beautiful?

Does the World Follow Physical Laws?

- With exception of creatures with free will, all other creatures solidly follow physical laws.

  Indeed, the borderline between free-willed creatures and ones without free will is vague. Viruses, for example, do not have cells but have only nucleic acid; producing nothing more than chemical reactions.

  We cannot completely predict the behaviors of the monad; however, the reactions toward chemical and physical stimulus are gradually being solved.

- Human beings have survived natural selection by studying the laws of nature.

- Although, having different level of skills in adjusting themselves to the laws of nature, every creature and animal has even unconsciously adopted the laws through natural selection. Their bodies have gradually become accustomed to the changes; as if they know all about the laws of nature.

Karl Popper, “If the physical laws of this world are autonomous, we are not free; if we are free, then the physical laws are not autonomous.” J.Barrow, *The Anthropic Cosmological Principle*.

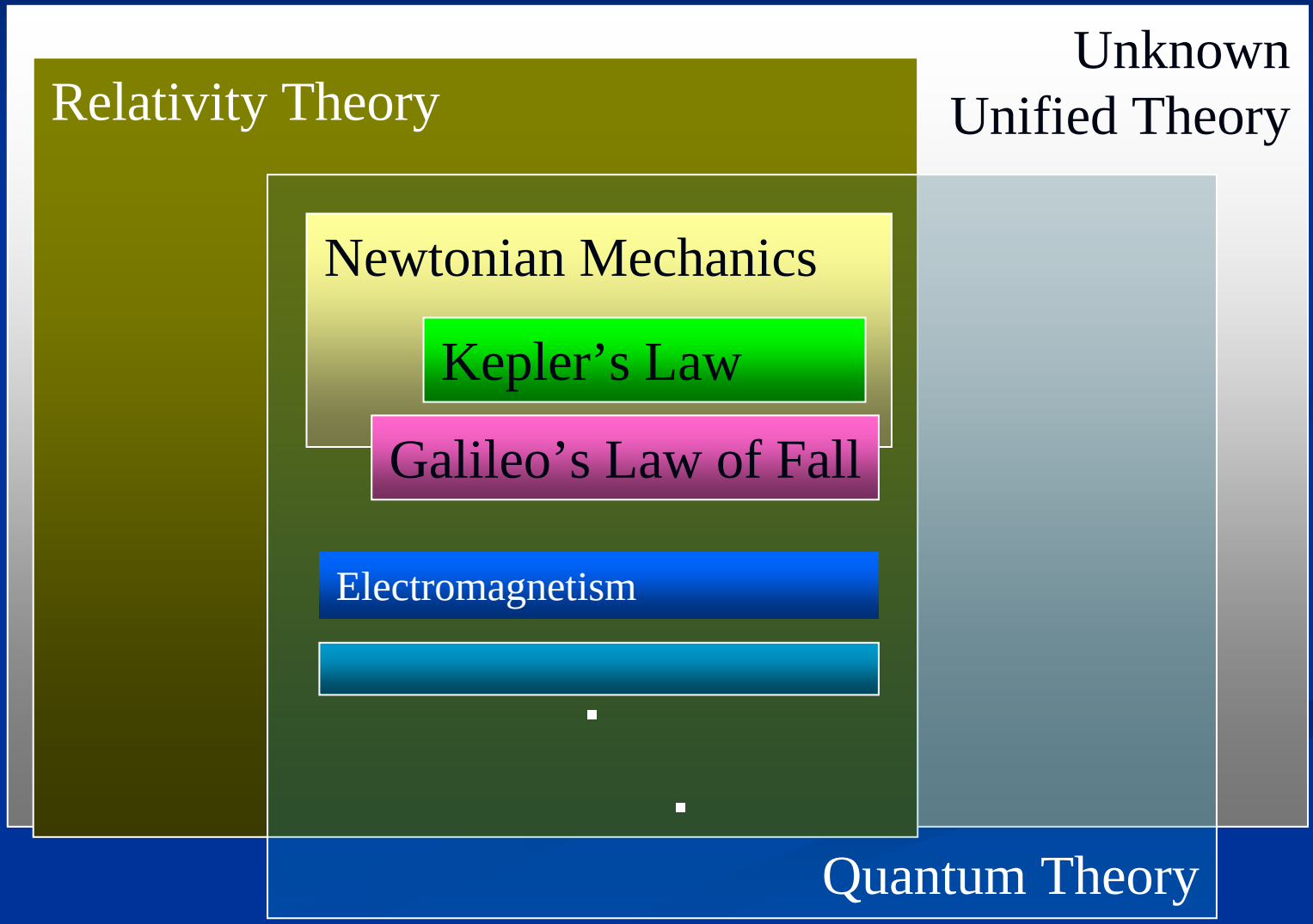
Laws and Theories of Nature

- Human beings have systematically organized information about the world of nature through their survival experiences and established physical laws [theories].
- The physical laws we have learned so far, are grounded on inconsistent theories only applied within limitations.
- The theories must be verifiable by experiments and observations.

- Are physical laws absolute principles? Are they the cause of all behaviors? Is physics the only means of finding the absolute principles that are already there? Tycho Brahe, "The law is the proof of God's existence."
- Are physical laws simply the provisional hypotheses of nature of its better benefits by human beings?

Karl Popper: The mechanism that makes unconditional scientific theories possible is that such theories can be derived from a combination of conditional predictions and existential statements specifying that the conditions in relation to the system being investigated are fulfilled.

Hierarchy of Physical Laws (the Truth).物理法則（真理）の階層性



Classical Mechanics (Newtonian Mechanics) and Determinism

Principia: Philosophiae Naturalis Principia Mathematica (1687)

Equation of motion:

$$m\frac{d^2x}{dt^2} = F$$

Force ***F*** equals the product of mass ***m*** and its acceleration d^2x/dt^2 .

The point of landing of a thrown ball can be predicted completely if given the initial conditions: ①the point of release the ball ② an initial velocity.

Every Equation of Motion is a Differential Equation

Given the initial conditions of an event, the rest of the time, development should be defined with completion.

The evolution of the universe is defined completely at the very first moment of creation; the very first impact by God.

We humans are the ultimate product of an evolutionary universe. And the very first seeding was the seed for humans. The last song of the universe was sung in the morning of creation

‡

Omar Khayyam (Persian poet and scholar). *Rubaiyat*

Sato. Terasawa. trans. *Uchyu no Mirai* :Nikkei Science.Tokyo. Japan: 1983.

In the Late 19th Century Physics was Considered to have Reached its End.

Newtonian mechanics: an establishment in mechanical observation of nature.

Analytical mechanics : Lagrange and Hamilton formulated the equation of motion and canonical theory, which are “works of art”.

Electromagnetism: the unified theory of electrics, magnetism, and electromagnetism was accomplished. E.g., Maxwell’s equation

Thermodynamics: formulation by application of partial differential equations.

Physics has fundamentally reached its completion by now. The application of physics should be further focused.

In 1900, Lord Kelvin gave a lecture "*Nineteenth-Century Clouds over the Dynamical Theory of Heat and Light.*"

"*beauty and clearness of theory*" was overshadowed by "*two clouds*, the null result of the Michelson-Morley experiment and the problems of blackbody radiation."

Lord Kelvin pointed out the presence of two clouds that overshadowed the clarity of physics in the nineteenth century: absence in detection of ether and blackbody radiation.

Apparently, the two clouds became solutions to modern physics; relativity and quantum theory were created.

Two Pillars of Modern Physics –Quantum Theory and Relativity Theory

- Modern physics was constructed on two theories: quantum theory and relativity theory.
- The basic science and applied technologies advanced these two theories especially on the quantum theory, which brought a revolution to the human society.

Atomic and Hydrogen Bombs
Nuclear Power Generation

Medical Technology | **Information Networks**

Agriculture | **Nuclear Energy**

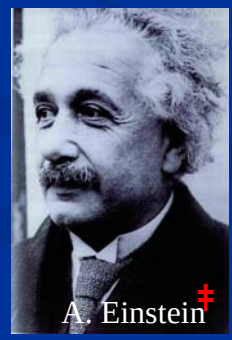
Environment | **Semiconductors**

Astronomy | **Chemistry** | **Biology**

We cannot live without quantum theory.

Outline of modern physics

Quantum Theory



Relativity Theory

Sato, Katsuhiko, ed. *Zukai: Ryoshi Ron*. Tokyo: PHP Research Institute, 2004 p.15

What is Quantum Theory?-Physical Laws that Govern Microscopic Systems

- Matter possesses dual particle-wave properties.
  Behavior of a particle can be obtained stochastically by solving the equation of traveling waves.
- Heisenberg uncertainty principle: $\Delta x \Delta p > h$

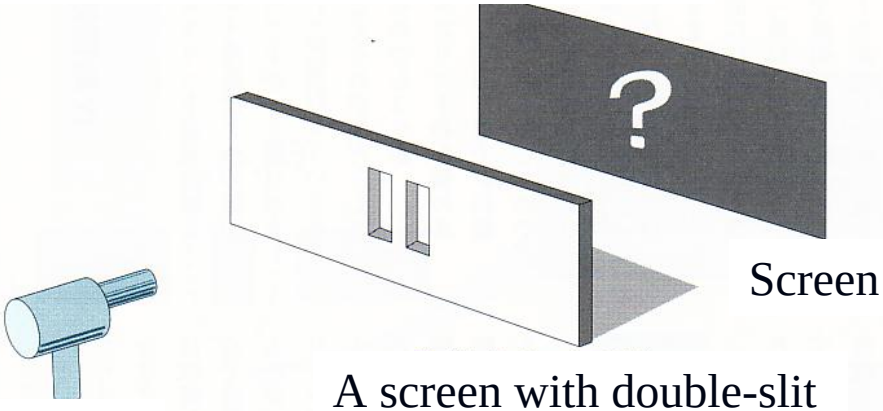
  Particle location(x) and momentum (p=mV) can be determined simultaneously only at a particular range.

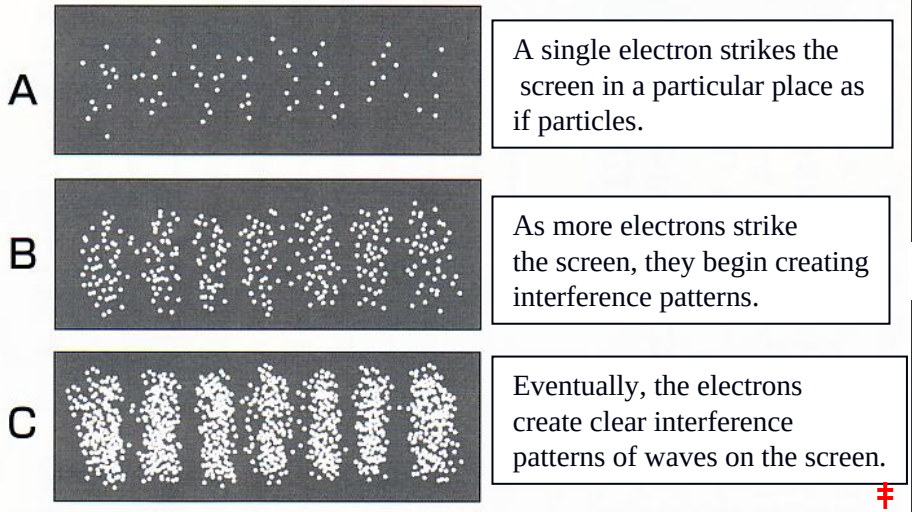
h: Planck constant

Physical laws can only stochastically predict the behavior of the physical world. There is no determinism.

A Single Electron Can Interfere as a Wave

A double-slit experiment of electrons

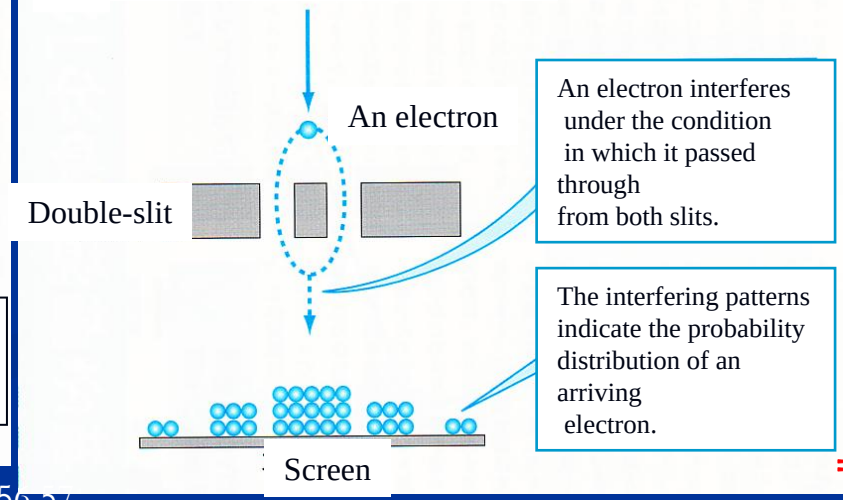




The same result can be obtained with a single electron fired by a very low-powered electron gun. This shows that a single electron behaves as a wave.

Self alteration of an electron

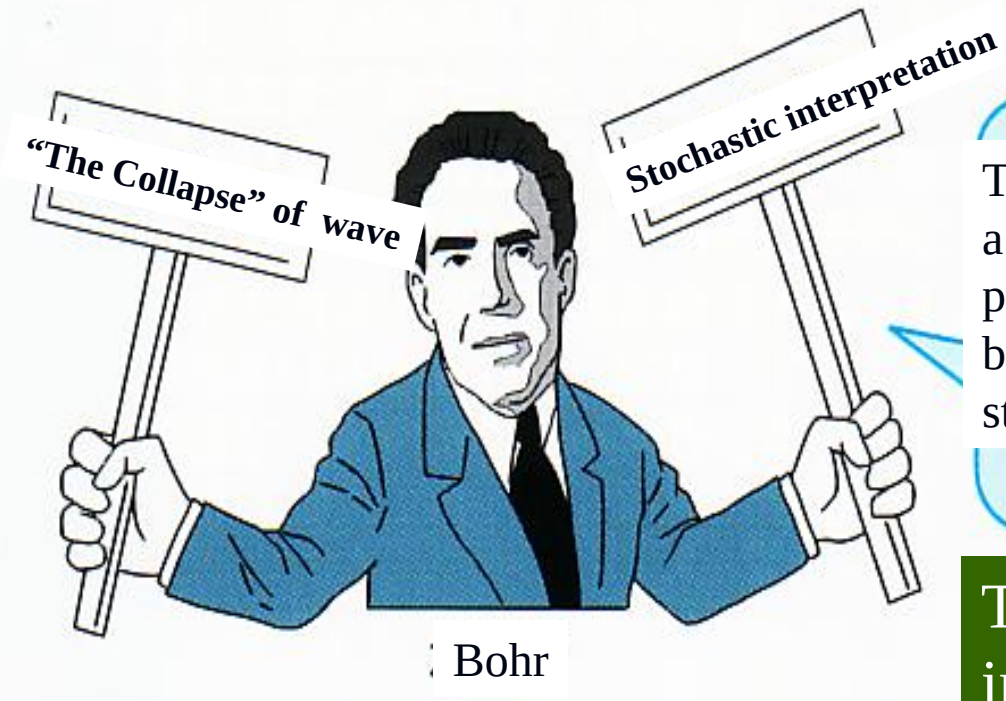
An electron interfering by itself



Sato, Katsuhiko, ed. *Zukai: Ryoshi Ron*. Tokyo: PHP Research Institute, 2004 p.56,57

What is a Wave?

Even though a single electron can interfere as a wave, the result is observed in a single point. Why?



The Copenhagen interpretation:
a method of understanding such complicated problems as the measurement of electrons, based on the collapse of waves and the stochastic interpretation of the electron.

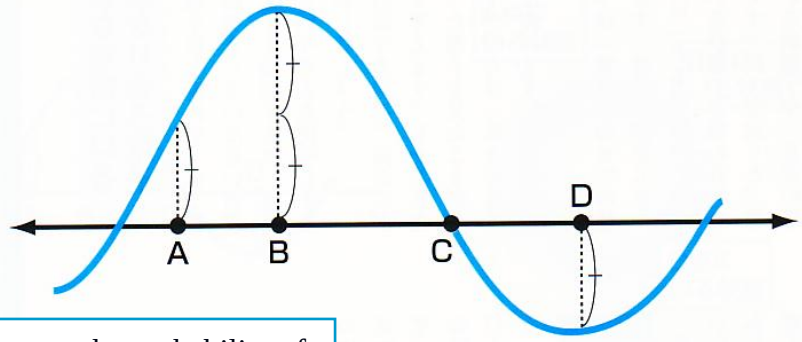
The most widely-accepted interpretation today.

Sato, Katsuhiko, ed. *Zukai: Ryoshi Ron*. Tokyo: PHP Research Institute, 2004 p.49

The Copenhagen Interpretation and the "Collapse" of Waves

A Wave's height is proportional to the detection probability

Stochastic interpretation of the wave function.



Suppose, the probability of detecting an electron at **A** was 10%.

40% Detection probability at **B.**
0% Detection probability at **C.**
10% Detection probability at **D.**

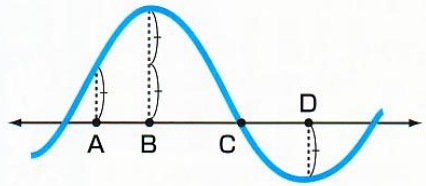
The square of the wave function ψ, a complex number, is proportional to the probability of a particle at position.

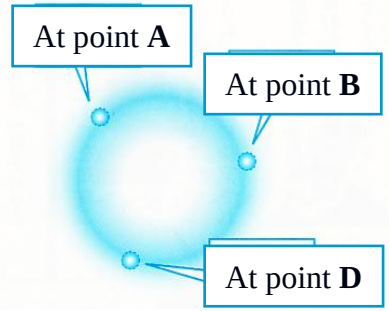
*Accurately, it is the square of the absolute value of the wave function.

Born ‡

An extending wave and a collapsed wave

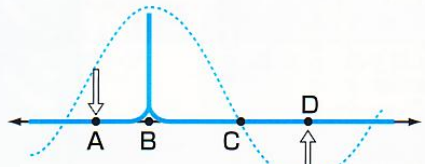
The wave is extending.





The electron wave is in the superposition of states until we observe it.

The wave is "collapsed".



As soon as we can catch the measurement of the electron wave, the wave collapses into a point.
An electron can only be detected in a point. ‡

Sato, Katsuhiko, ed. *Zukai: Ryoshi Ron*. Tokyo: PHP Research Institute, 2004 p.47,49

What is Quantum Theory?- Physical Laws that Govern Microscopic Systems--

- **Matter possesses dual particle-wave properties.**

  The behavior of a particle can be obtained stochastically by solving the equation of traveling waves.

- **Heisenberg uncertainty principle: $\Delta x \Delta p > h$**

  Particle location(x) and momentum (p=mV) can be determined simultaneously only at a particular range.

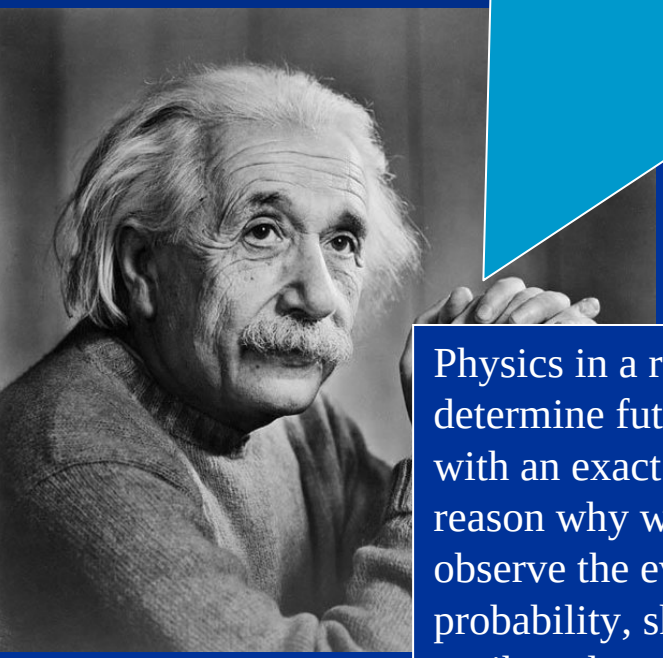
  h: Planck constant

Physical laws can predict the behavior of the physical world only by probability. There is no determinism.

Interpretation problem: quantum theory gives expected results based on calculations. However, there is no practical problems, the interpretation of waves remains perplexing. Do waves “collapse” when observed?

1. Do Waves Produce a Probability Distribution?

God does not play dice with the universe.



Physics in a real sense must determine future events with an exact accuracy. The reason why we can only observe the events in probability, should be attributed to an incompleteness of the quantum theory.

Sato, Katsuhiko, ed. *Ryoshi Ron Wo Tanoshimu Hon*. Tokyo PHP Research Institute, 2000. p.143

S. Hawking: All the evidence supports the view that God is a habitual gambler; he does play dice at every opportunity. *Chronology Protection Conjecture*,1991

2. Do Waves Appear to Collapse in the Observer's Frame? Do Waves Exist in Superposition of States until Observation?

Schodinger's Cat

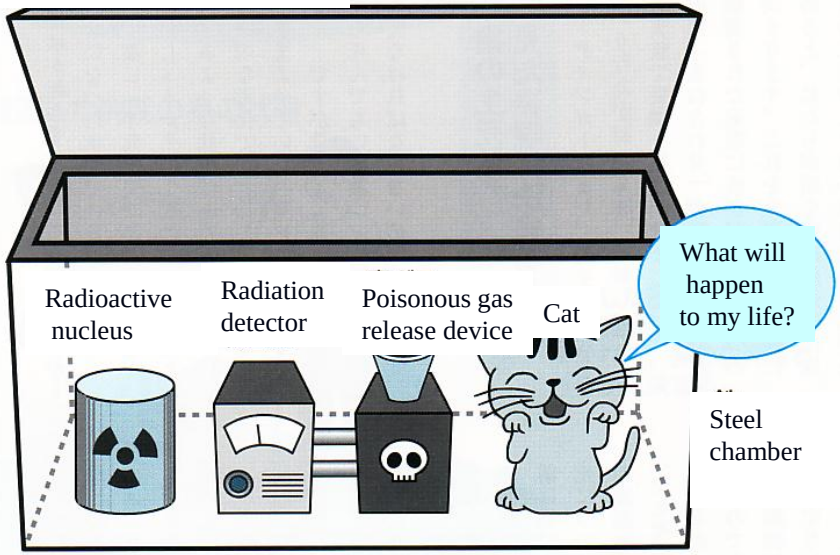
Schrodinger

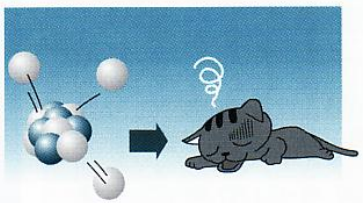
According to quantum theory, systems can be in the superposition of states (dead-alive). Only when a system is observed, the states collapses into one or the other state. The cat's fate is decided only when we open the chamber and actually see the cat, seems to somehow disregard reality.

‡

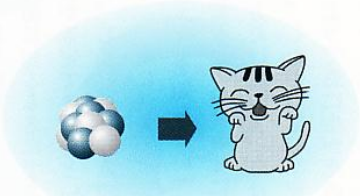
Sato, Katsuhiko, ed. *Ryoshi Ron Wo Tanoshimu Hon*. Tokyo PHP Research Institute, 2000. p.197

Schrodinger's Cat





If the radioactive nucleus starts to decay, the poisonous gas will be released and kill the cat.



If the radioactive nucleus does not decay, the poisonous gas will not be released thus the cat stays alive.

‡

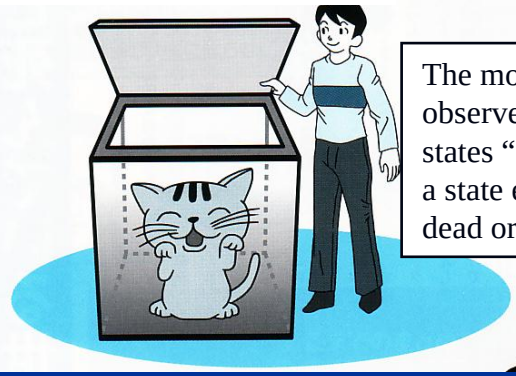
Sato, Katsuhiko, ed. *Zukai: Ryoshi Ron*. Tokyo: PHP Research Institute, 2004. p.71

What is the condition of the cat?

Before observation.

The cat is in a superposition of states; being both dead and alive.

The moment of observation.



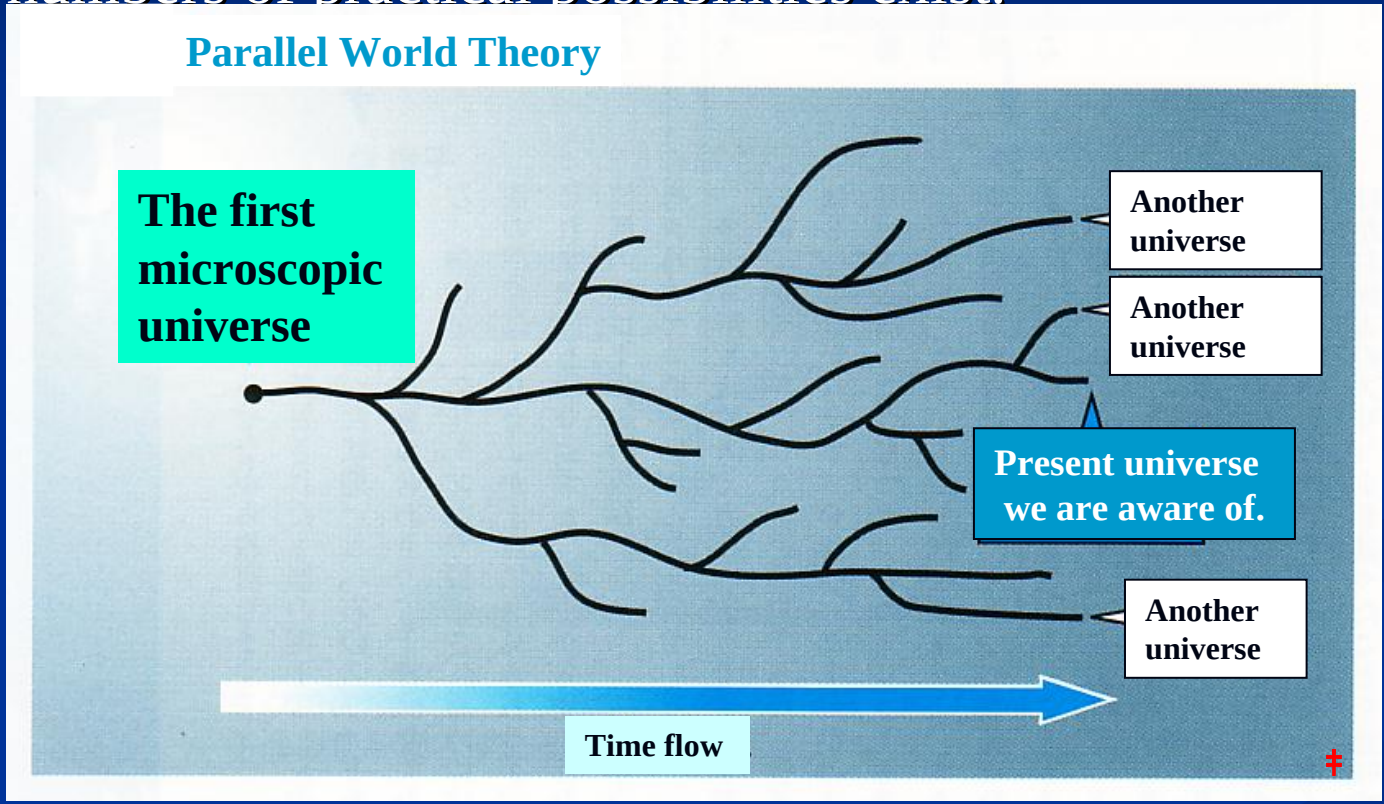
The moment the cat is observed, the dead-alive states "collapses" into a state either dead or alive.

‡

Sato, Katsuhiko, ed. *Zukai: Ryoshi Ron*. Tokyo: PHP Research Institute, 2004. p.73

The Many-worlds Interpretation of Quantum Mechanics H. Everett

- The world (universe) endlessly splits into many worlds whenever numbers of practical possibilities exist.



Sato, Katsuhiko, ed. *Zukai: Ryoshi Ron*. Tokyo: PHP Research Institute, 2004. p.79

There is an infinite number of worlds existing with each being mutually-unobservable but equally real.

The Many-worlds Interpretation Seems Bizarre though consistent in that it avoids the collapse of waves.

- Schrödinger's cat can be explained without considering the collapse of waves.
- Even if the theory of relativity allowed time travel to be possible, the many-worlds interpretation states that it may be impossible to travel backward into time, thereby avoiding the grandfather paradox. (see Lecture 3)
- Everett predicted the existence of a collection of multiple universes better known as the mulitiverse.

Richard Feynman, "Newspapers once said that there were only twelve people with a true understanding of the theory of relativity though, I never thought there had been such a time…. but when it comes to quantum mechanics, you can say no one really understand it." J. Barrow, *Universe that Discovered Itself* , 2000. ‡

The Evolution of Universe? The Problem of Free Will?

- Failure in observer-observable dualism:

  The observer is also a part of the universe. According to quantum cosmology, the wave function of the universe follows differential equations, and evolves deterministically yet, the obtained outcome remains probabilistic.

- Quantum theoretical probability has introduced a more diverse world :

  The behavior of matter follows the laws of physics but the probability in the context of quantum theory may have brought more diversity into the world. This fundamental principles of physics and its mathematical models become the **warp** and **weft** of our beautiful physical world. The mathematical models we mean by science of complex systems: spontaneous symmetry breaking, self-organization, dissipative structures, attractor, and chaos.

- Free will: The probabilistic nature of quantum theory cannot be explained in terms of single-valued deterministic ways. The human brain, at the level of chemical reactions, is a quantum system rather than a deterministic one. The question is whether our brain system is attributed to the mathematical models of the physical laws in the same diversity systems of the universe.

R. Penrose : Consciousness has a unity, thereby the brain mechanism for producing consciousness should also have a unity property. Quantum interference satisfies this condition.

Penrose, Rogers. *The Large, the Small and the Human Mind: Kokoro wa Ryo-shi de Katareruka?*(translated by Kazuyuki Nakamura), Tokyo: Kodan Sha, 1998.

A Unified Theory of Physical Laws

- The essence of physics: To explain all creatures and every phenomenon in the world of nature with as simple and as few principles as possible.

  The invention of just so many particular laws for each phenomenon lacks in its predictability.

The history of physics is the history of the unified theory.

①Gravity: Newton unified the forces that make an apple fall, and the one act among celestial bodies.

②Electromagnetic forces: Maxwell eventually unified the forces of magnets, magnetic forces, and electric forces.

Unification of Fundamental Theories in Physics

Einstein's attempt: Unified field theory 1932

Unification of ①Gravity and ②Electromagnetic forces enables us to solve the question of the whole physical system by a single theory.

Somewhat premature : although our universe seemed to be in motion with two forces acting on the system; gravity and electromagnetic forces, there are actually two other fundamental forces existing.

③Weak forces and ④Strong forces are found in the atomic nucleus.

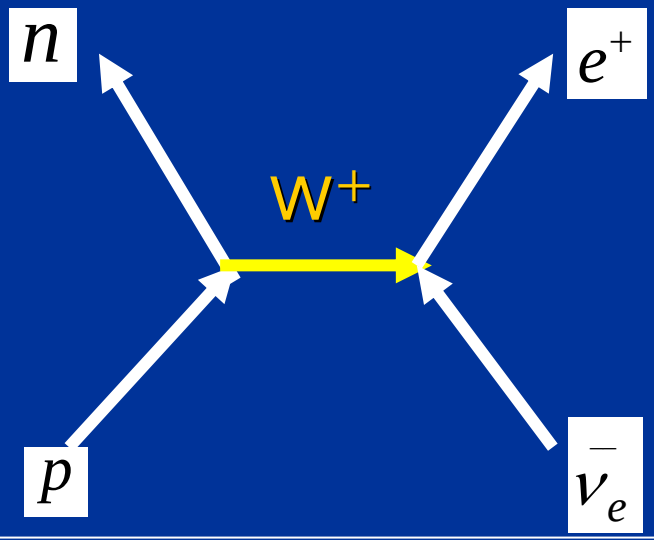
③Weak Forces

- Weak forces：responsible for beta decay

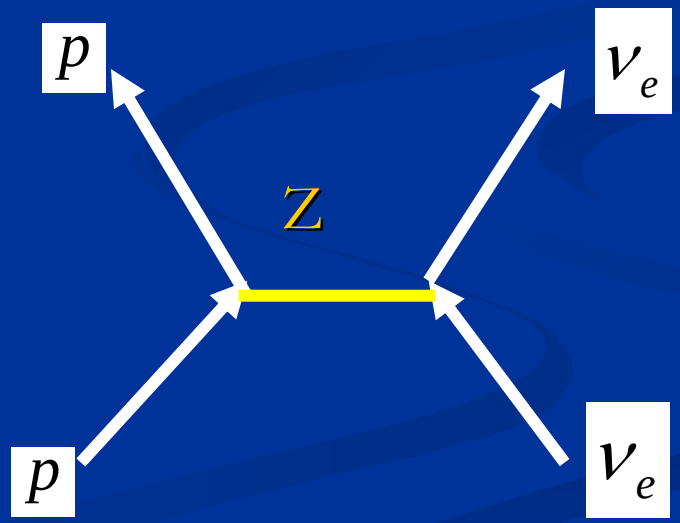
  E.g. Neutron's beta decay

  $n \rightarrow p + e^{-} + \nu_e$ W^+ ,W^-, and Z bosons are the mediators

  Neutrino interacts only via weak forces and gravity.



KamiokaNDE's supernova neutrino detection.



SNO's (Canada) solar neutrino detection.

④ Strong Forces

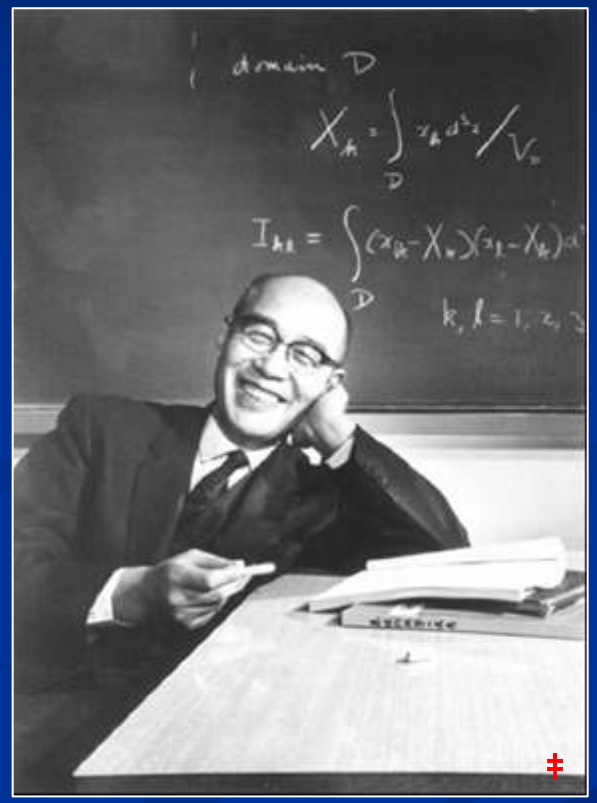
- Strong forces : the forces that bind the nucleons (protons and neutrons) in the nucleus and nucleus into the nuclei.

Yukawa's meson theory (1934)

- Mesons mediate forces in nucleons

  Both nucleons and mesons are made of quarks, so in the smaller scope, strong forces are the forces that act on quarks.

  Gluons are the mediator of forces.



The first Japanese to be awarded the Nobel prize.

Strong Forces are the "Color Forces"

Quantum Chromodynamics

- Chromodynamics is the generalization of electrodynamics
- Electric charge: + and −. (+ binds with – to become neutral)
- Color force: +, red, green, and yellow (the three primary colors) and −.

  anti-red anti-green anti-yellow

  (The three primary colors bind together, or the opposite colors bind together to become neutral.)
- The mediator particle of forces

  Electrodynamics: photon (one type)

  Chromodynamics: gluon (eight independent types)

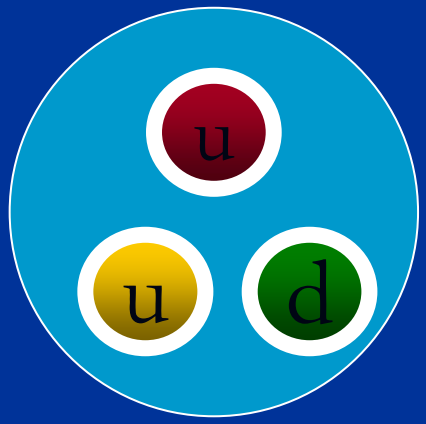
Note: the expression color has nothing to do with paints and other "colors" used in everyday life but rather represents the special quantum properties of charges.

The Nucleons and Mesons are Composed of Quarks

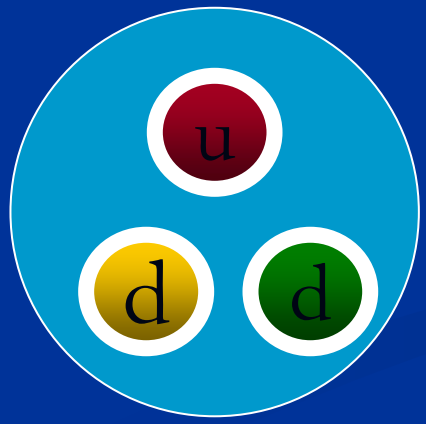
Quarks come in six independent types with each composed of three different colors of quarks.

Up	u, u, u,	Charm	c, c, c,	Top	t, t, t,
Down	d, d, d,	Strange	s, s, s,	Bottom	b, b, b,

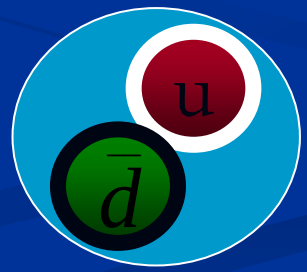
Photon



Neutron

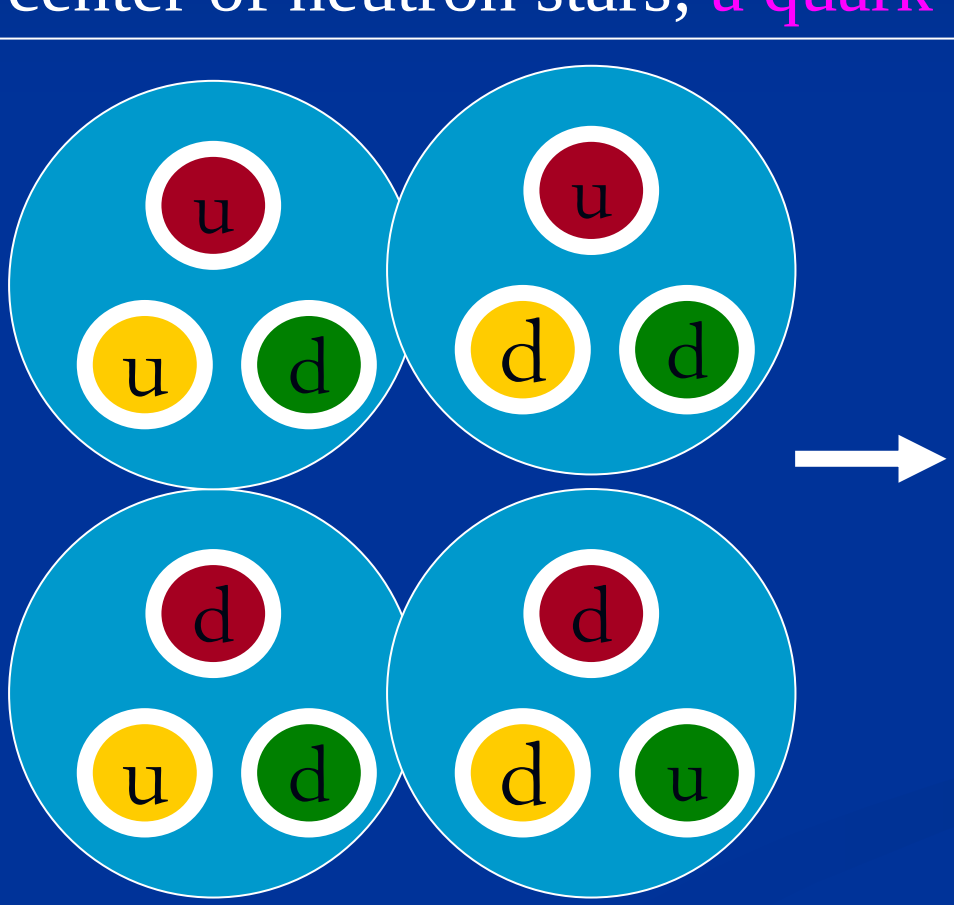


π^+ Meson



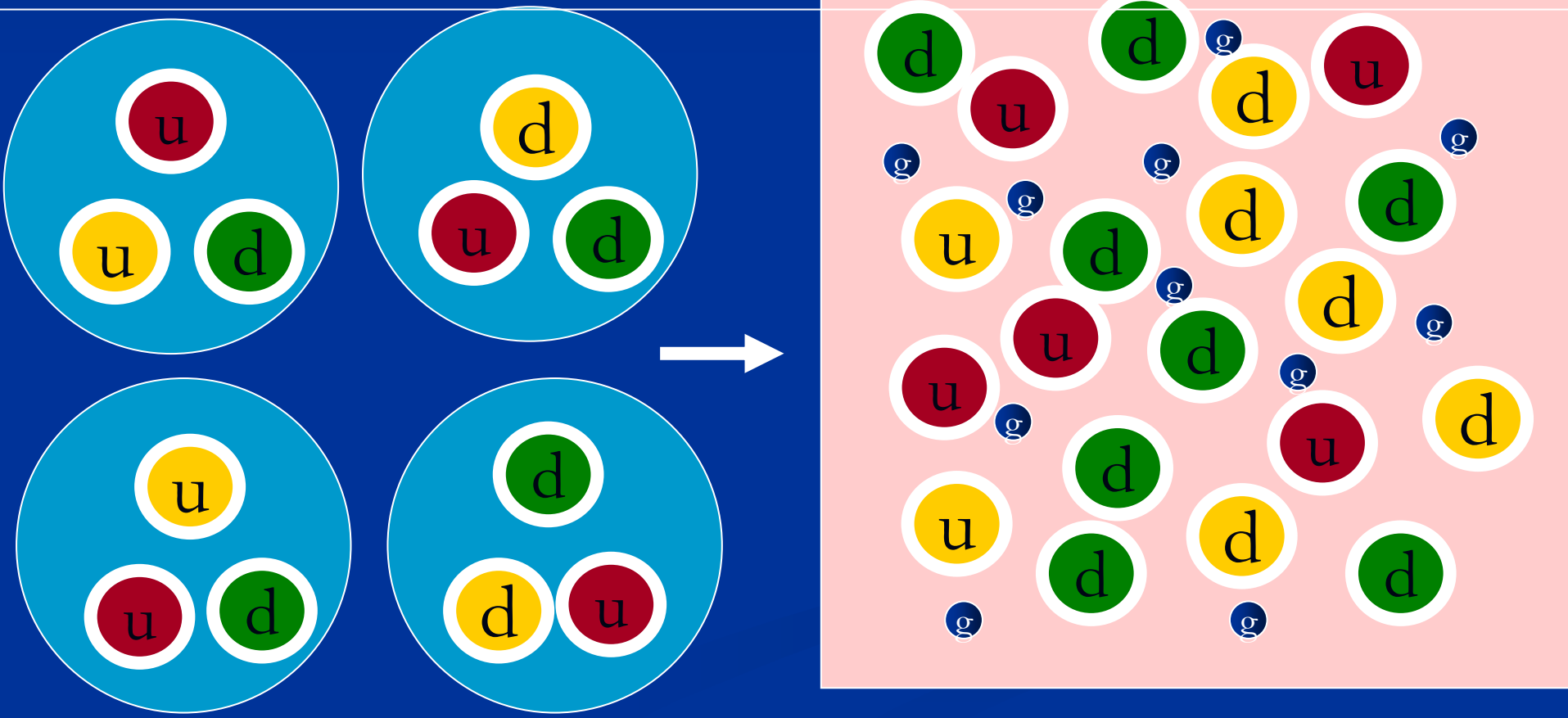
Quark Matter

When matter reaches a high density, the nucleons begin to overlap to form quark matter. Quarks may be found in the center of neutron stars; a quark star.



Quark-Gluon Plasma

When matter reaches a high enough temperature, as if during the primordial state of the universe, the nucleons will melt to produce quark-gluon plasma.



The Unified Theory of All Forces—Einstein's Hope—

The four forces that govern nature:

1. Gravity
2. Electromagnetic forces
3. Weak forces
4. Strong forces

Unify all four forces into a single theory.

An Ultimate Unified Theory Remains Incomplete

- For a while after Einstein's work, researches on the unified theory had been thought as not having a clear objective.
- The first step toward the unified theory (It is not the unification of electromagnetic force and gravity)

  The unified theory of "Electromagnetic forces" and "weak forces" was achieved.

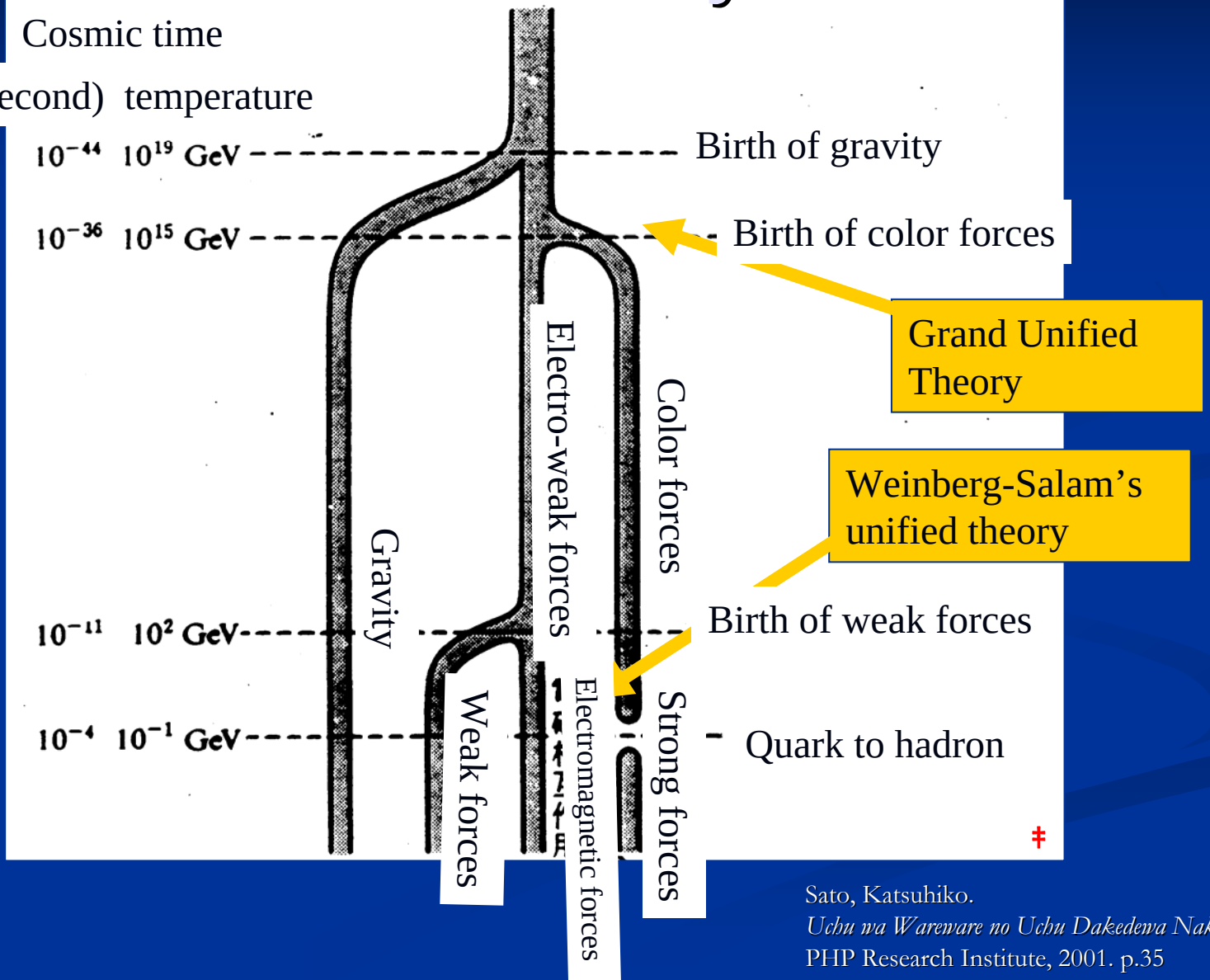
  Weinberg-Salam theory (1967) also experimentally verified (1983): Nobel Prize (1979)

  These days the two forces are unified, and called "electro-weak forces".

- The second step toward the unified theory

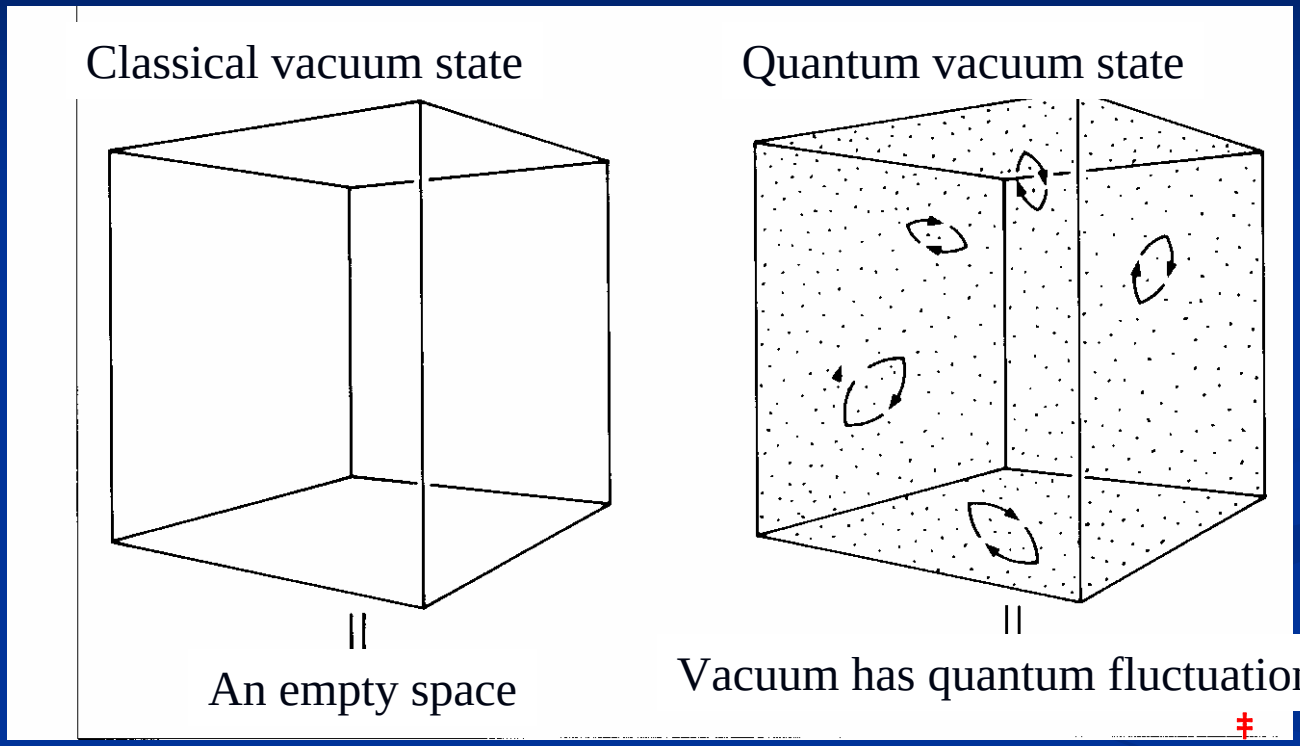
  The unification of "electro-weak forces" and "color forces". The Grand Unified Theories (GUTs) were proposed but, none of them have experimental proof.

The" Evolution of Force" According to the Unified Theory 統一理論の予想する「力の進化」



Sato, Katsuhiko.
Uchu wa Wareware no Uchu Dakedewa Nakatta. Tokyo PHP Research Institute, 2001. p.35

“Vacuum Phase Transition” is Based on the Unified Theory (WS Theory).



Sato, Katsuhiko. *Uchu 96% no Nazo.* Tokyo: Jitsugyo no Nihon Sha, 2003 p.137

“A vacuum” is an entity with physical properties.

The phase transition occurs in a “vacuum state” just as water changes to form ice.

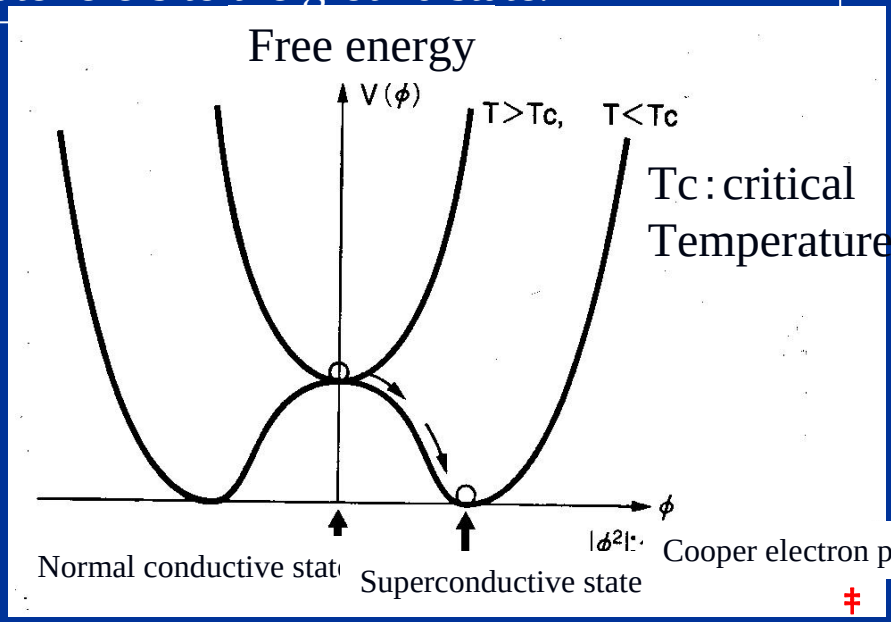
Vacuum Phase Transition

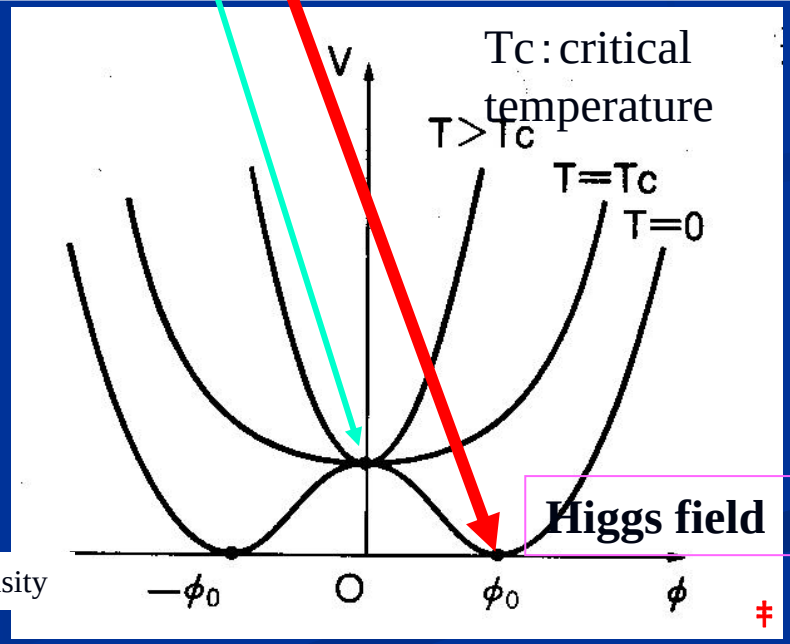
The unified theory can be an analogy for the theory of superconductivity.

The Ginzburg-Landau theory indicates the spontaneous symmetry breaking of “a vacuum” causes photons to retain “superficial mass” inside the superconductor.

In condensed matter physics, the vacuum state refers to the ground state.

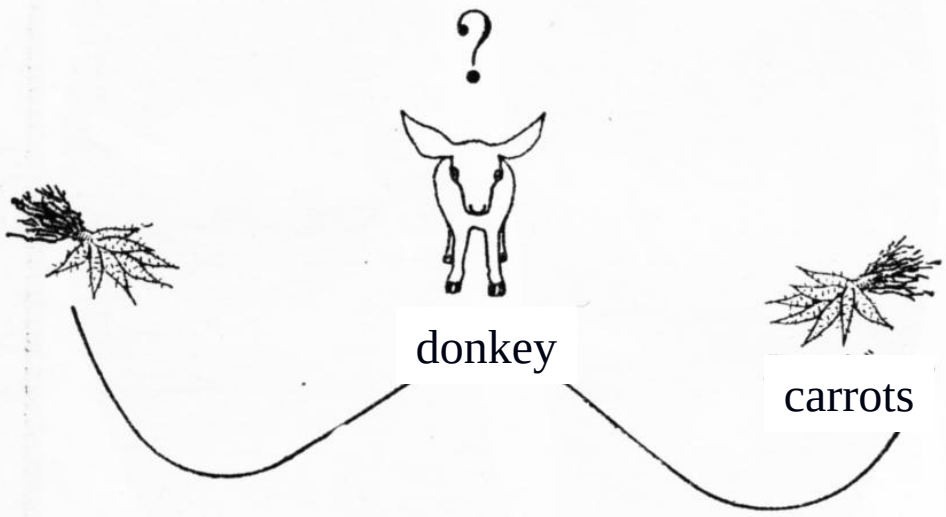
In the WS theory, there is the existence of a ***Higgs field*** that describes the symmetry of a vacuum. This spontaneous symmetry breaking causes ***W and Z bosons*** to hold *huge mass* , that were *originally zero mass*.

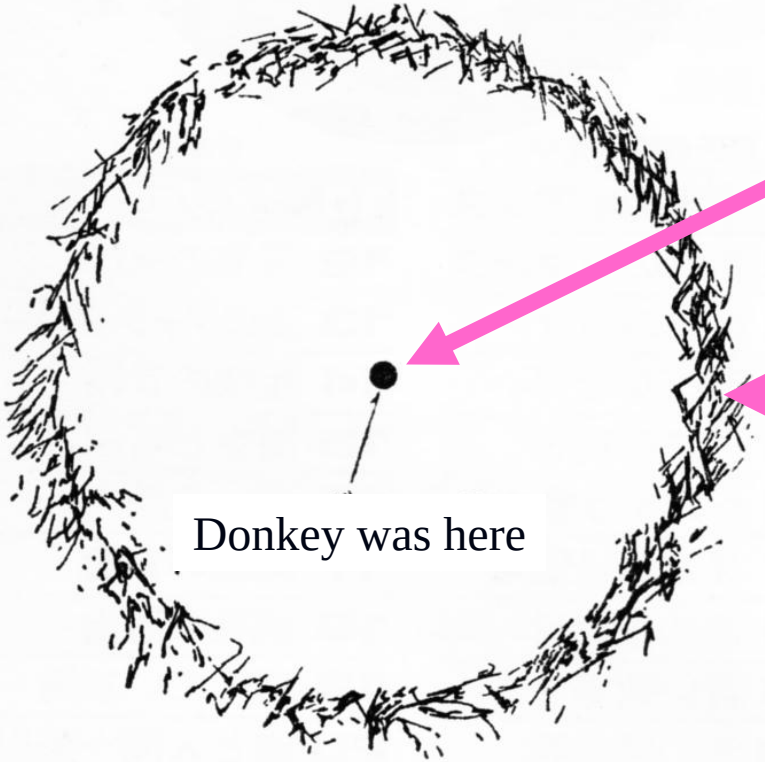




Sato, Katsuhiko. *Uchu 96% no Nazo.* Tokyo: Jitsugyo no Nihon Sha, 2003 p.141

The mass of W and Z bosons reach roughly 100GeV. The forces become short-range and weaker.





Spontaneous Symmetry Breaking

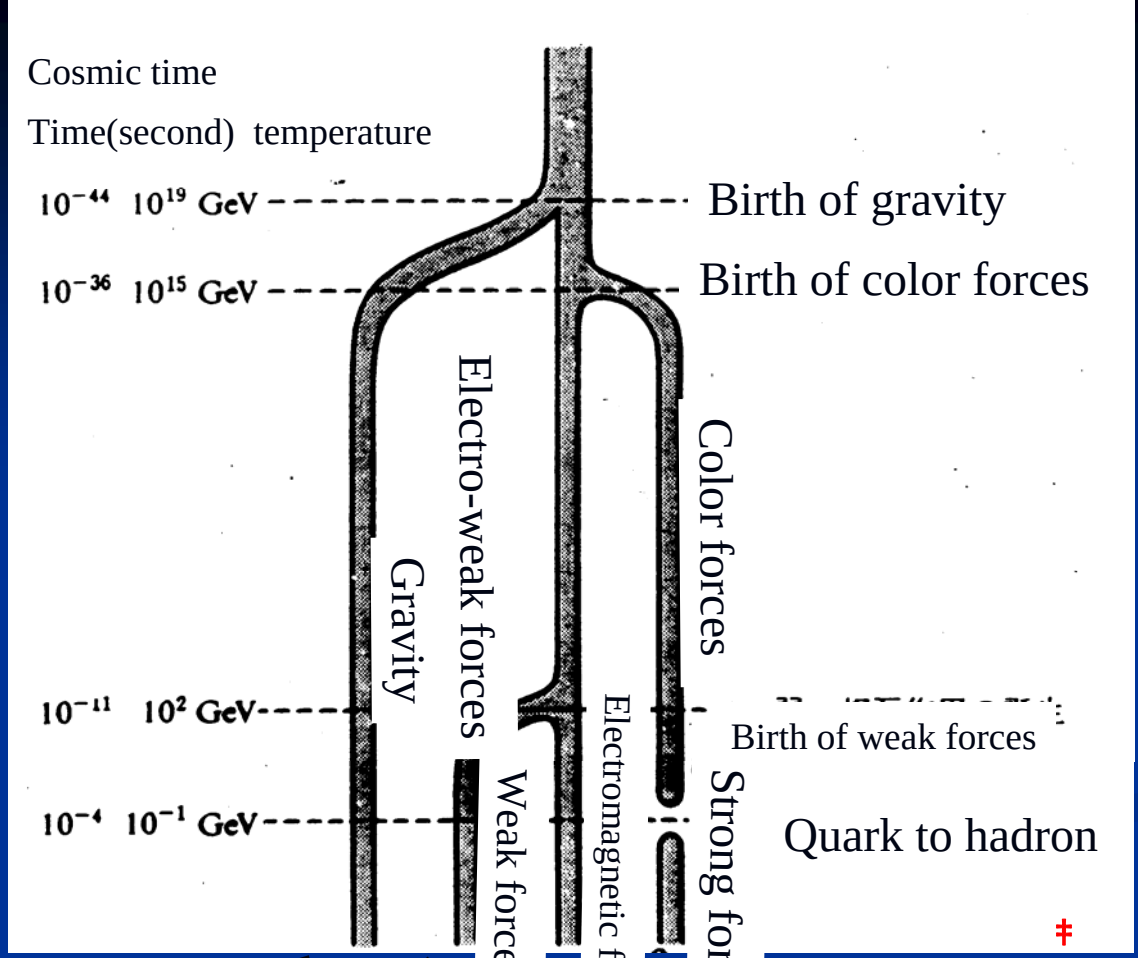
Physical laws strictly follow bilateral symmetry.

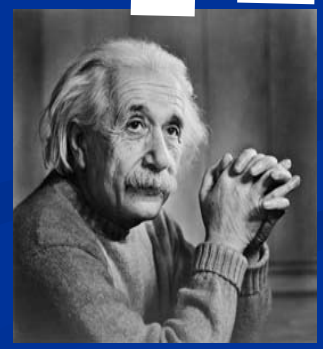
The symmetry will ultimately be broken due to its unstable state.

Sato. *Nature*., 1969.

The "Evolution of Force" According to the Unified theory

The force splits into branches as it proceeds toward evolution. It is the same evolutionary process observed for living creatures.





Sato, Katsuhiko. *Uchu wa Wareware no Uchu Dakedewa Nakatta.* Tokyo: PHP Research Institute, 2001 p.35

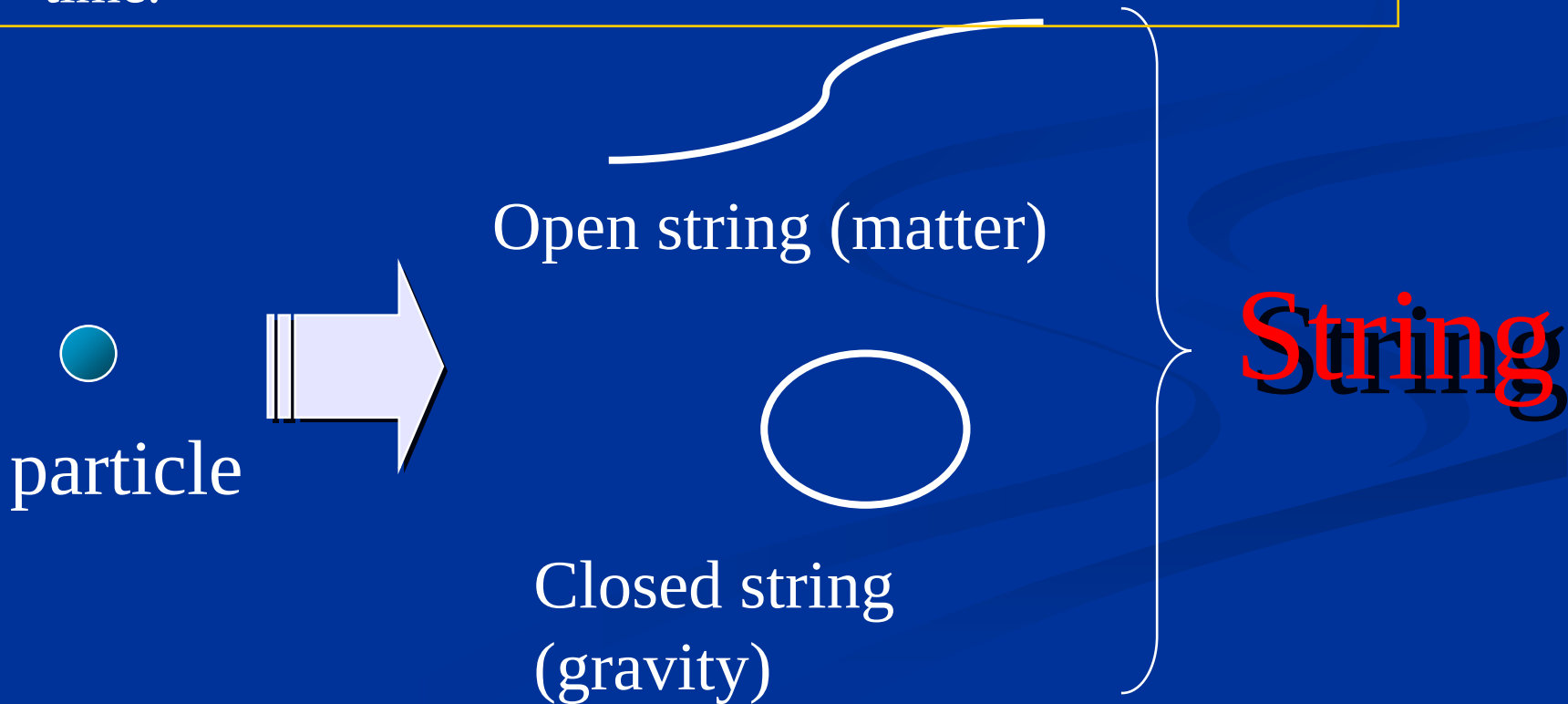
The Theory of Everything Evolves in the Universe

Only one unified force may have existed at the time of creation. This one force could have split into branches just as with the evolution of living creatures. This may have eventually formed the known four forces of the present.

However, the unified theory of all forces, a theory of everything, remains incomplete.

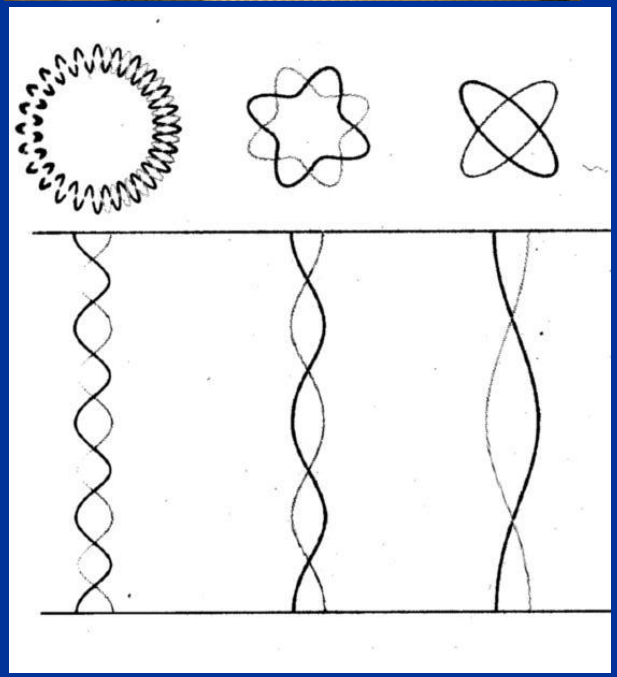
Superstring Theory/Brane Theory

1. Matter particles and mediator particles are all made of string.
2. The string belongs to ten- or eleven-dimensional space-time.

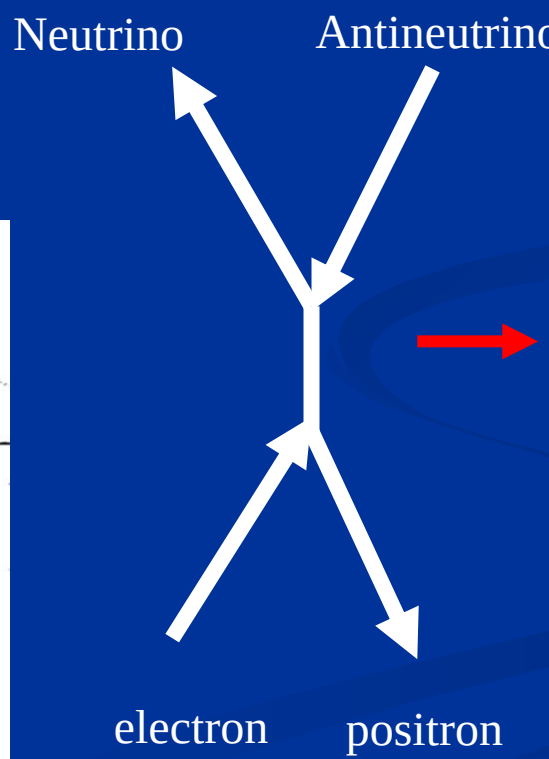


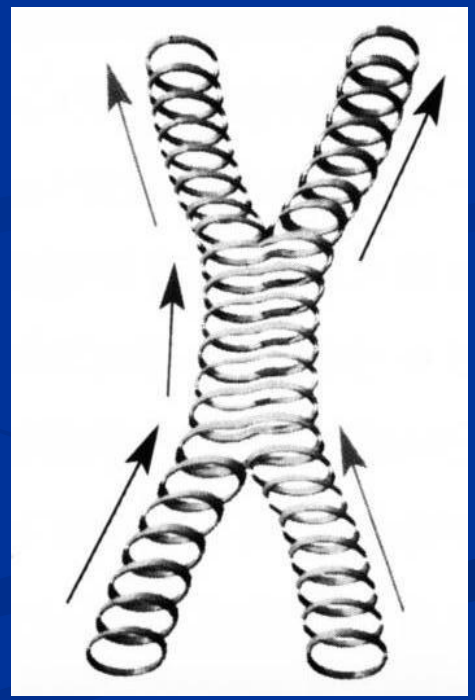
Oscillation and Recombination of Strings Describes the Reaction Between All Particles and a Particle .

Particles of different types and masses.



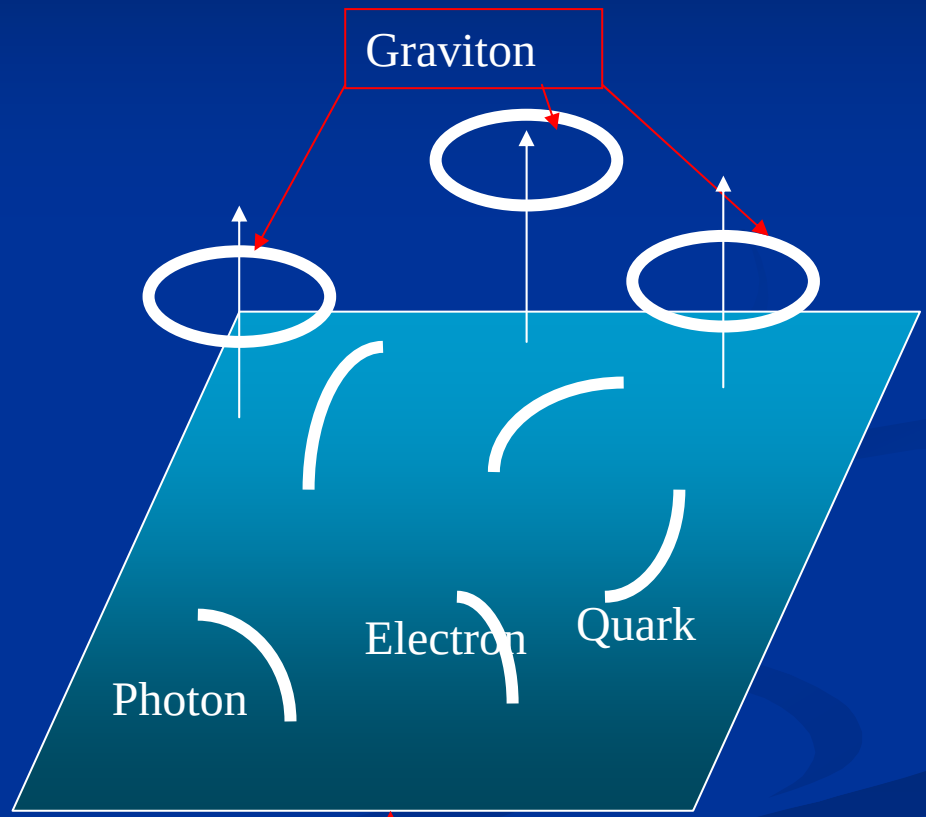
Reaction of a particle





Brane Theory (1995)

- The extremes of the string are stuck on the membrane, and cannot escape from the membrane.
- Exceptions include the graviton, a closed ring, that mediates gravity.
- Matter is confined in the braneworld yet, gravity is valid outside the brane.



The braneworld: Three-dimensional space, “the membrane” in the ten-dimensional space-time, is our universe.

The Measurement of Gravity at an Infinitesimal Distance

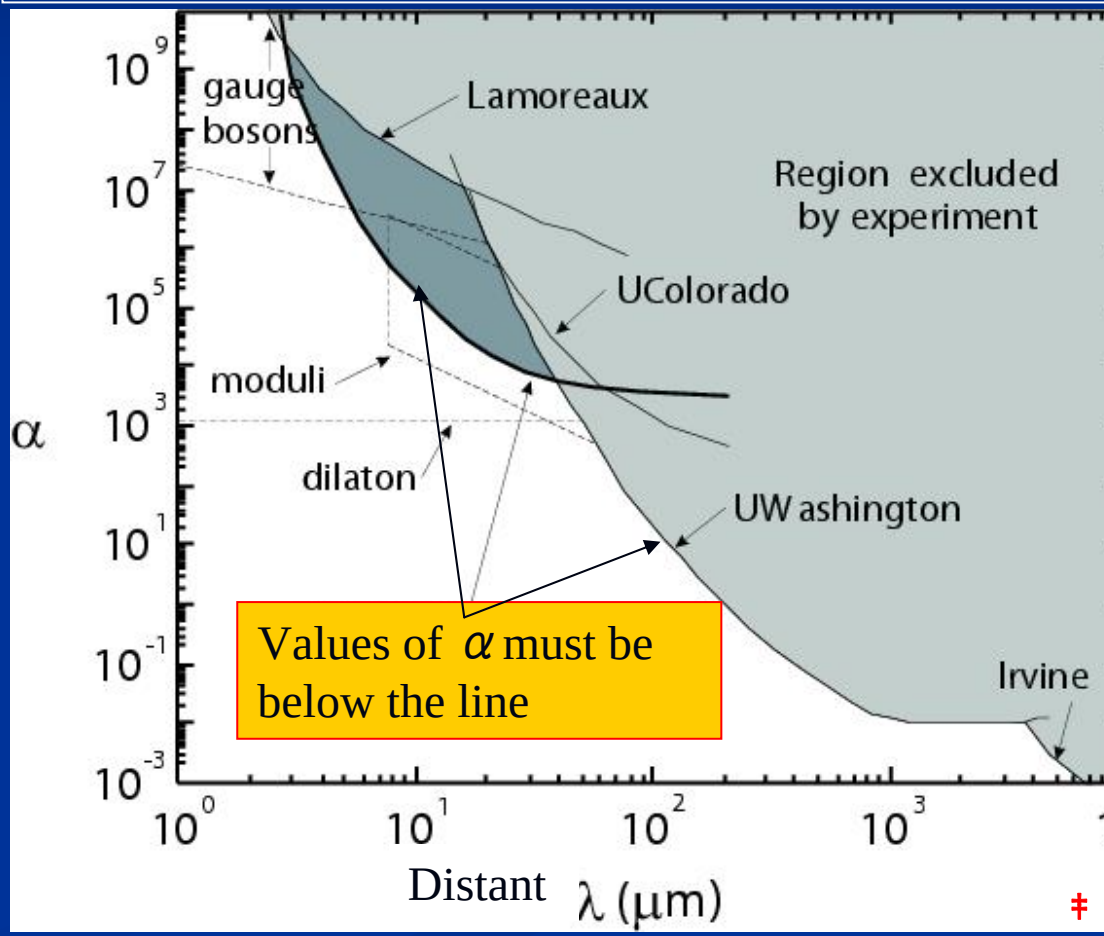
Gravity strays from Newton's Law of Gravitation at the distance shorter than the "thickness of membrane λ".

Gravitational potential

$$V = -G\frac{m_1 m_2}{r}(1+\alpha \cdot e^{-r/\lambda})$$

α : the effect by gravity in excess dimension.

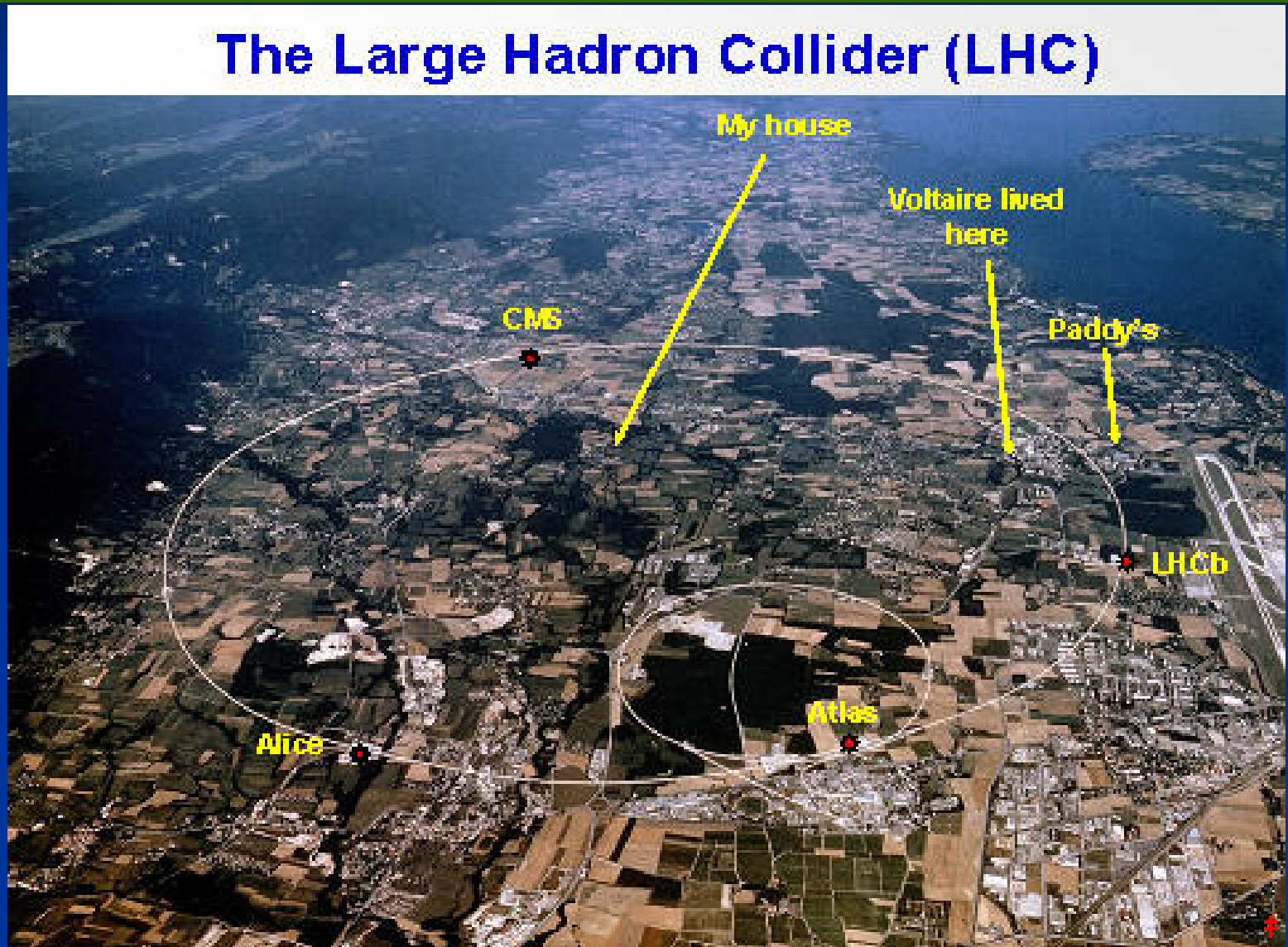
Conditions of α by experiment

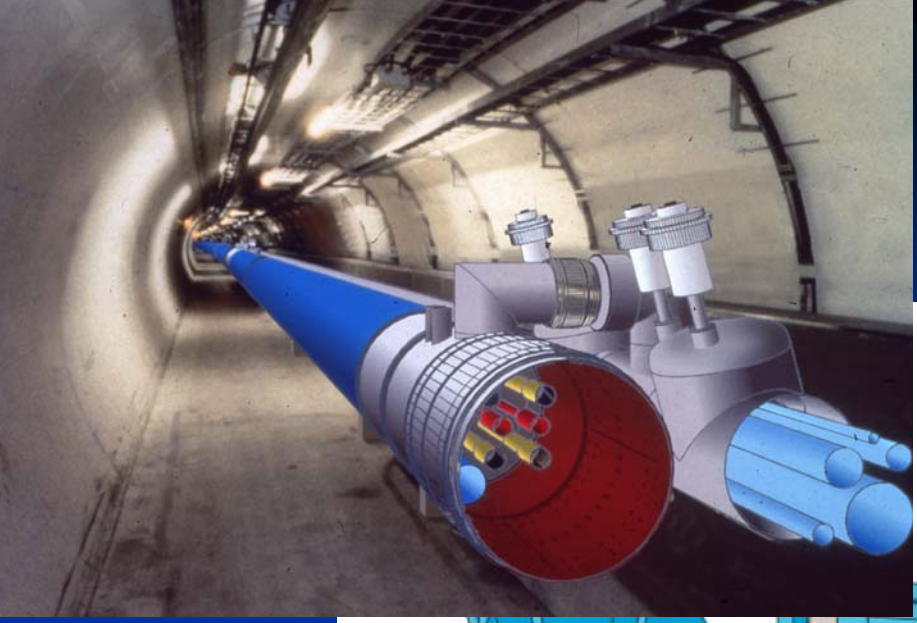


"New Experimental Constraints on Non-Newtonian Forces below 100 mum"

Chiaverini, J. et al. Physical Review Letters, 90, 1101, 2003

LHC may be able to Form a Black Hole. Black Hole Evaporation may be Observed.

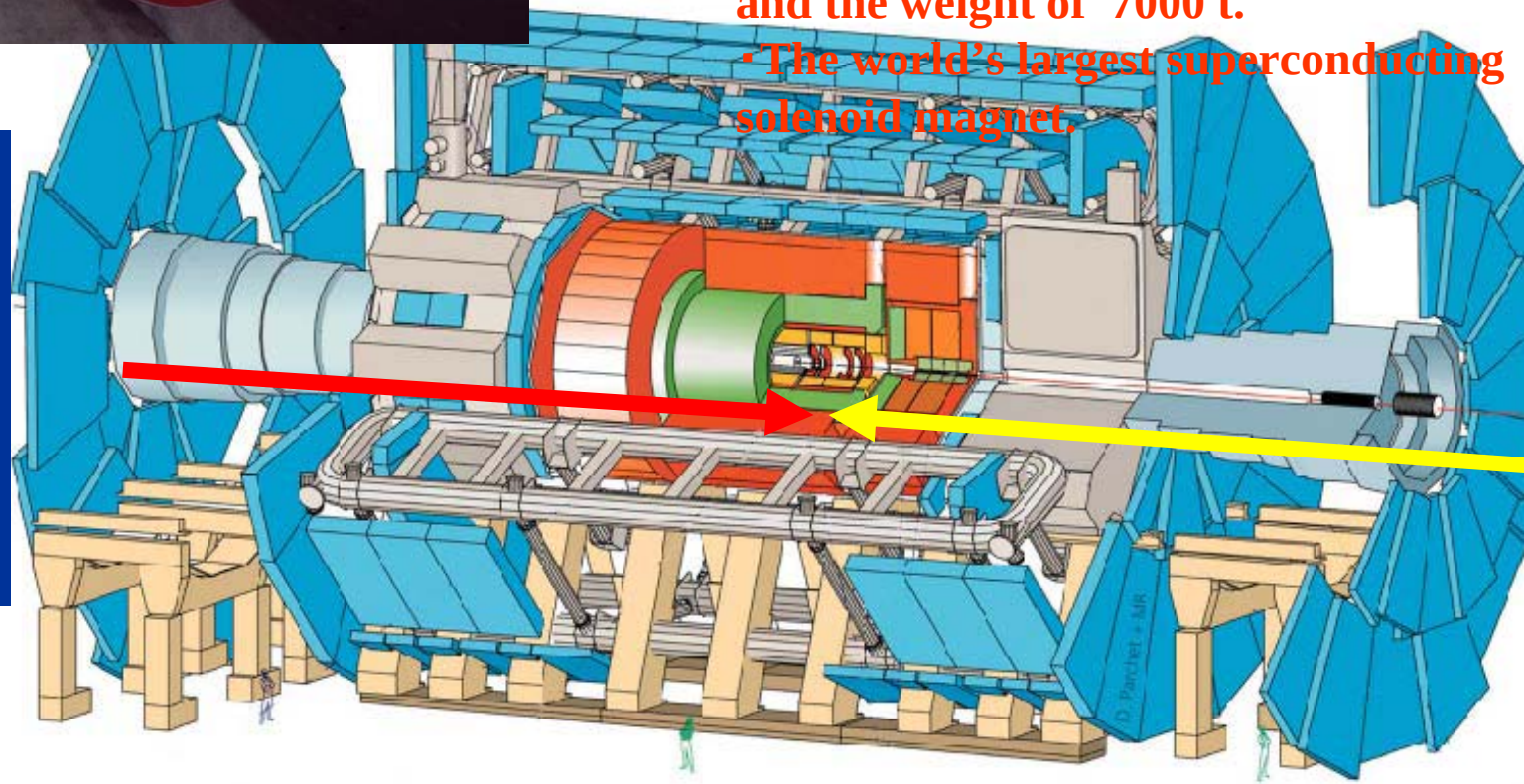




The research team from The University of Tokyo collaborated on the experiment.

ATLAS detector

- **Diameter of 22 m , total length 44 m, and the weight of 7000 t.**
- **The world's largest superconducting solenoid magnet.**

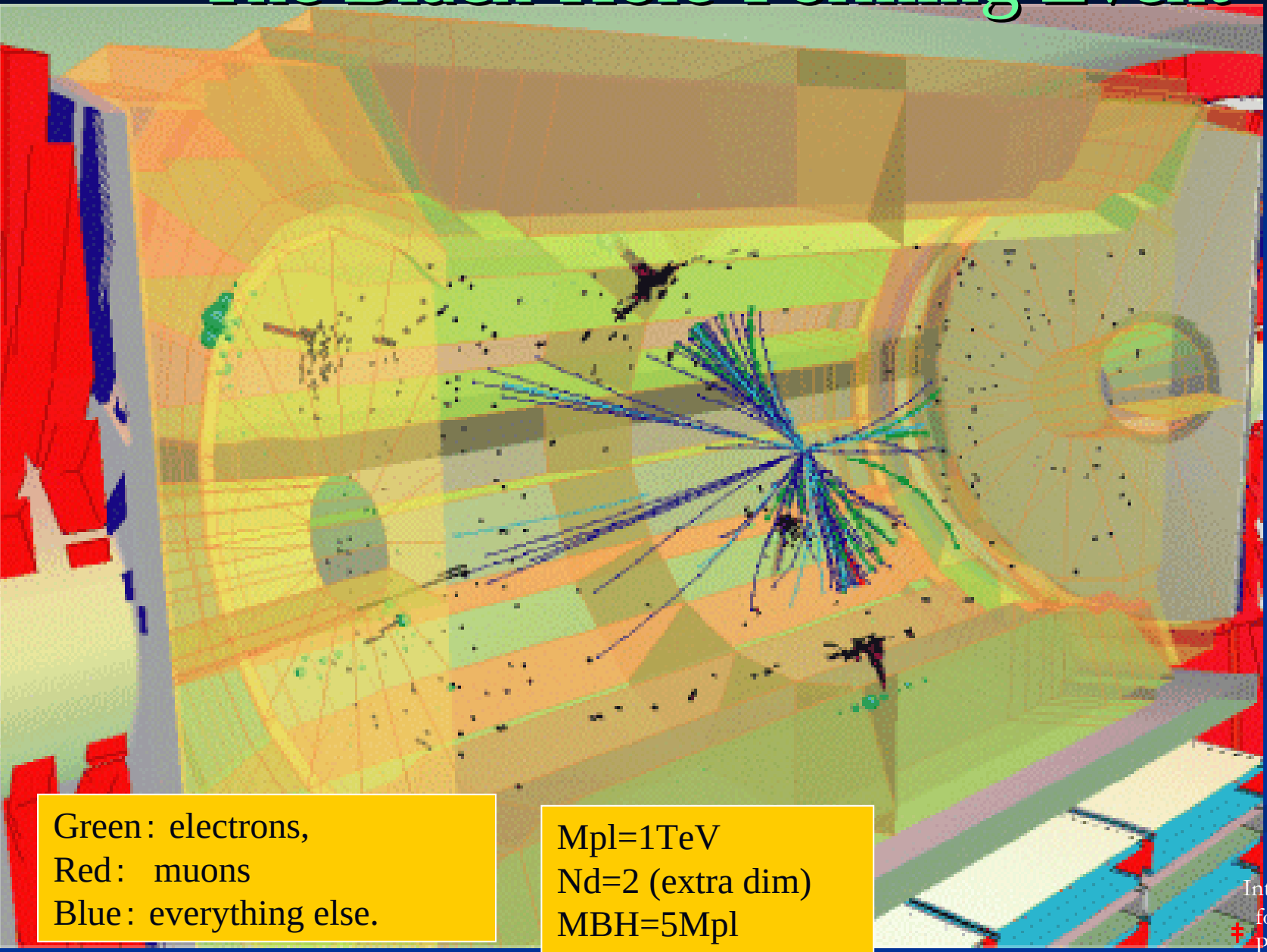


Purpose: to collide the elementary particles and construct a black hole.

International Center for Elementary Particle Physics
Tomio Kobayashi

‡

The Black-Hole-Forming Event



Green : electrons,
Red : muons
Blue : everything else.

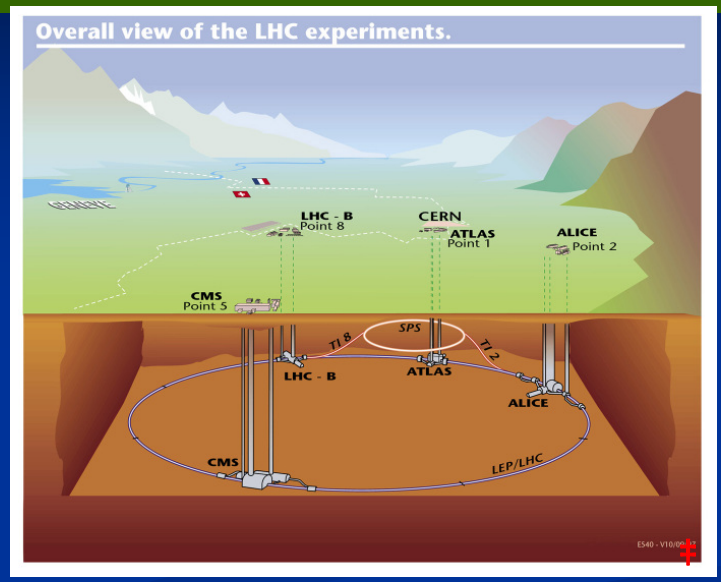
Mpl=1TeV
Nd=2 (extra dim)
MBH=5Mpl

International Center
for Elementary
Particle Physics
Tomio Kobayashi

Does A Theory of Everything Exist?

- Physics has searched for a unified theory that may be able to describe the birth of all creatures. Although, superstring theory is thought of as the closest answer to this question, it is controversial.
- However, does a unified theory truly exist? Are we able to break the wall of approximation and eventually reach the exact answer?

Matryoshka doll



CERN: http://public.web.cern.ch/Public/Welcome.html

ILC http://www.interactions.org/cms/

The Theory of Everything and the Fundamental Constant

- Suppose ultimate theory existed, then how many fundamental constants (parameters) would be involved?
- Are there any fundamental constants, that may constitute the symmetries of space and time as well as geometric quantities?
- If the theory exists, then what is the fundamental constant?
  Is it the number of dimensions of space-time? Is it the magnitude of the force? Is it Planck's constant? The speed of light? The energy scales of the four branched-off forces? Or, is it the mass of quarks, leptons, and neutrinos?
- Why is such value taken?

E.g. the magnitude of the electromagnetic force

Fine structure constant: $\alpha \equiv e^2 / \hbar c = 1/137.033989561\cdots$

The Idea of the Human Principle

- The present laws of the universe and the physical constants are designed for human beings to be created. Only the slightest difference in the magnitude of electromagnetic forces, strong forces, …would not attribute the birth of human beings.
- Only the universes that create an entity of perception (intellectual soul; human being) are recognized. Other universes are not recognized.

In order to create a similar universe where we belong, we need to prepare for an extremely small topological space with a small volume. 「R. Penroes, *Kokoro-ha Ryo-shi de Katareru-ka?* (1998)

$$1 / 10^{10^{123}}$$

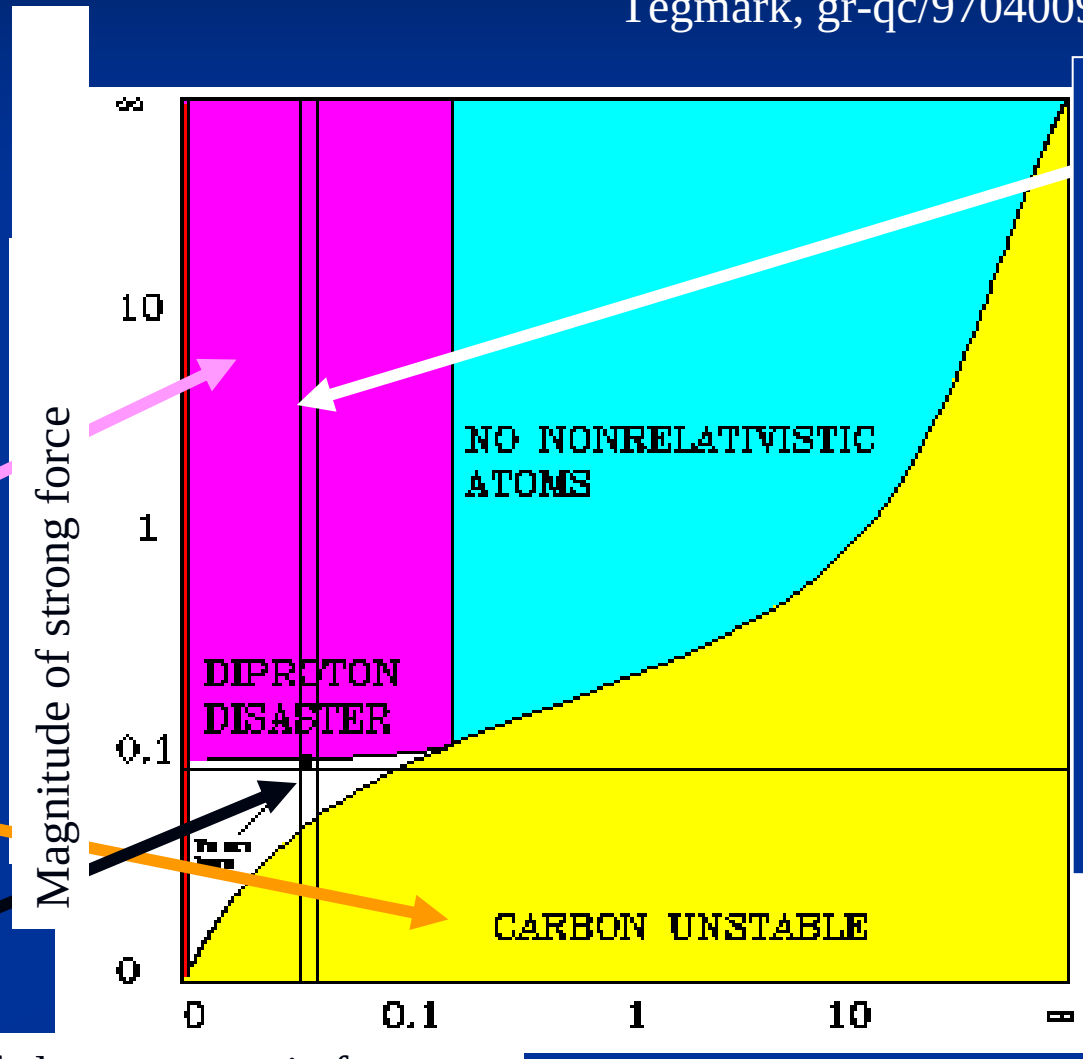
Is the Physical Constant Meant for the Creation of Human Beings?

The dimension of space: if the degree is greater than three, the electrons collide into the nucleus, the planets into the sun.

- Helium 2 can exist. No hydrogen is left in the Big Bang.
- No stable particles. No existence of carbon.

Present value

Tegmark, gr-qc/9704009



From the coupling constant of the grand unified theory

Why Are Physical Laws So Beautiful?

- The structure and laws of the physical world are derived from simple principles, symmetries, and mathematical consistencies.
- ・In the real world, e.g., (n, p, and e) quark-lepton symmetry. ・The law of motion is derived from the principle of least action.

Beauty in the Einstein's general relativity theory:

1) Principle of general relativity

(Physical laws can be written in the same form for all types of different coordinate systems.)

2) Principle of equivalence (Equivalence in gravity and accelerated motion)

Such simple principles explained above yield the beautiful laws of space and time in physics.

What is Beauty?

- Evolutionary Psychology: Our mind is a product of evolution.

  We feel pleasant sensations regarding the phenomenon and actions that involve leading our lives and prospering and having offspring, while we feel unpleasant regarding the opposite phenomenon. All such feelings are inscribed on our genes during the process of natural selection.

E.g., The freshness of nature, a clear blue sky, and the glistering stars above. (These represent a good environment). A Symmetrical structure. (Stability). A well-proportioned face. (Health).

Whenever we human being come across useful laws of nature for survival, these laws are inscribed on our genes during the process of natural selection, so that we feel beauty and learn pleasure in the laws of physics.

Beauty is Truth, Truth is Beauty

John Keats (1795-1821)

Beauty is not necessarily truth, but truth can be seen in beauty.

Note

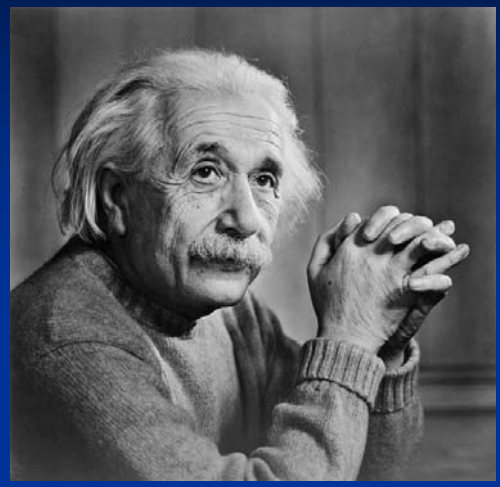
Our brain is creatively designed to organize and systematize the information we receive. Although, it is a necessary byproduct of our creative brain, we often attempt to discover order and patterns in irregularities somewhat by force.

Quotation by Zhuangzi

原天地美、
達万物理

Zhuangzi

Quotation by A. Einstein



A normal adult never stops to think about problems of space and time. These are things which he has thought about as a child. But my intellectual development was retarded, as a result of which I began to wonder about space and time only when I had already grown up.