Centennial Celebration: QM, QFT & More

Colloquium @ Brookhaven Forum 2025
Launching the Second Century of Quantum Physics

October 22, 2025

Tao Han
Pitt PACC, University of Pittsburgh

PITTPACC · PITTSBURGH PARTICLE PHYSICS ASTROPHYSICS COSMOLOGY CENTER ·

unesco

INTERNATIONAL YEAR OF
Quantum Science
and Technology

QuantumFest

Celebrating the International Year of Quantum Science and Technology with events at the intersection of art, science, and fun.

APS | JOINT MARCH MEETING AND APRIL MEETING
Global Physics Summit

March 16—21, 2025, Anaheim, CA and virtual

Schedule > Quantum Jubilee

Family Friendly | Intl. Year of Quantum Sci. & Tech.

Quantum Jubilee

10:00 am — 7:00 pm, Saturday March 15

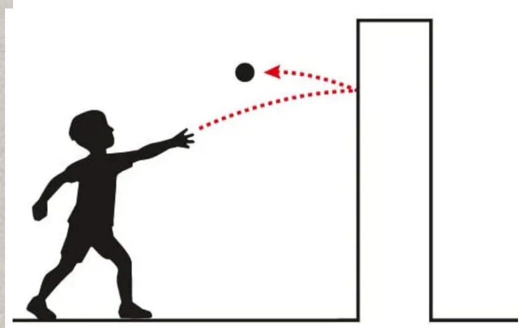
Nobel Prize in Physics 2025
Congratulations to three APS members

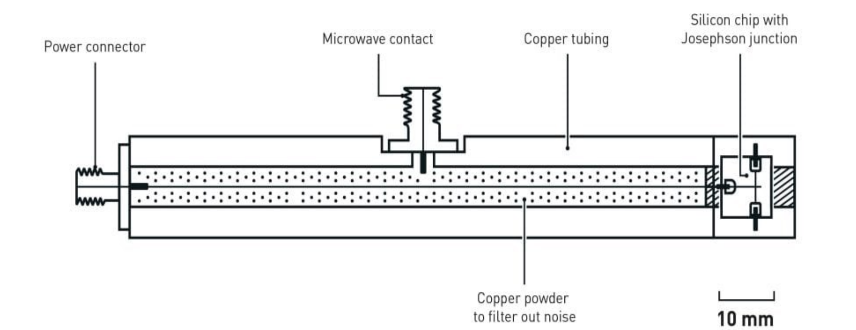
John Clarke
University of California, Berkeley, USA

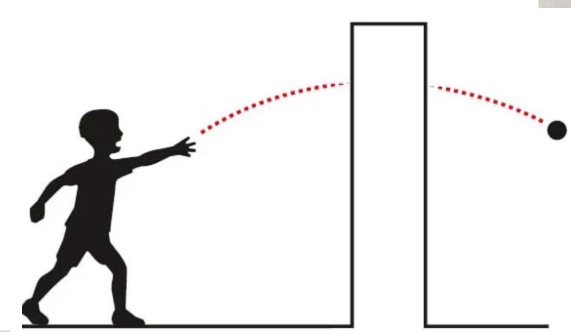
Michel H. Devoret
Yale University, New Haven, CT and
University of California, Santa Barbara, USA

John M. Martinis
University of California, Santa Barbara,

"for the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit"





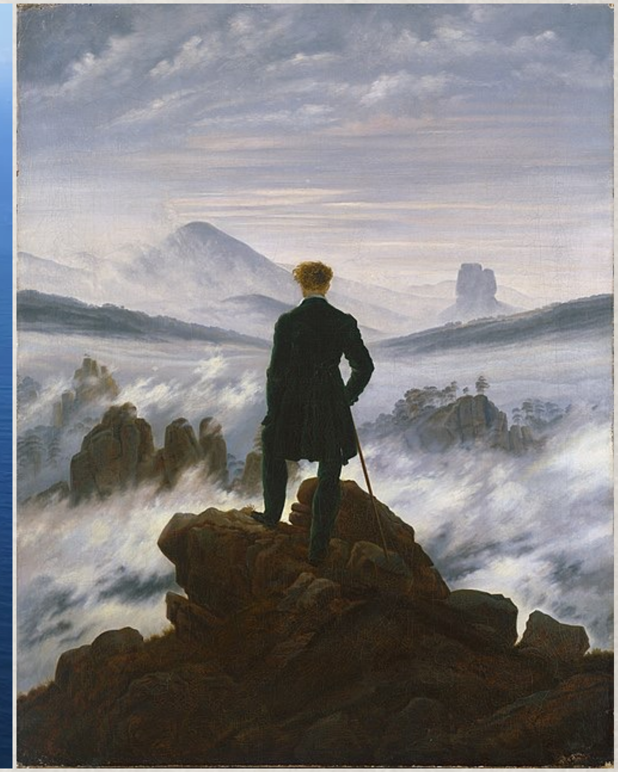


Quantum mechanics rules!

Talk Contents

- The "absurd" quantum phenomena
- Our quantum world
- Pushing boundaries of human knowledge

100 years ago in this remote island Helgoland, North Sea



Werner Heisenberg, 23, in vacation to recover from his severe hay fever, proposed a radical formulation to calculate the atomic spectral lines, that revolutionized the understanding of the sub-atomic world.

The “umdeutung paper” & the Matrix Mechanics

Heisenberg 1925

- Give up the unobservable orbits (x) and momentum (p)
- Focus on observable spectral lines, intensities …
- Follow the “correspondence principle”: classical – quantum correspondence in large quantum numbers
- Establish selection rules & time-evolution

Heisenberg-Born-Jordan 1926

- Established non-communitive relations

$$[\hat{x}(t), \hat{p}(t)] = i\hbar$$

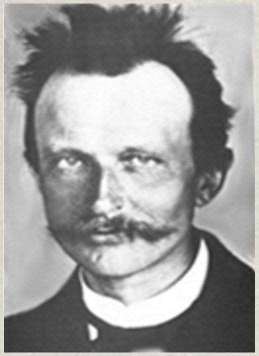
.

- The matrices as non-commuting observables

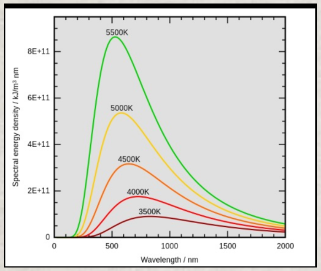
Lessons learned:

- Be creative and think outside of the box!
- Don’t be shy to ask for vacation!

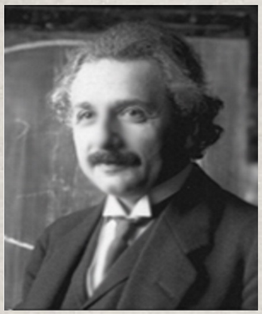
Top 10 Early Contributors to QM



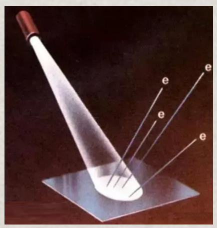
Max Planck: Planck constant: black-body radiation 1900 (1918)



$$I(\nu, T)d\nu = \left(\frac{2h\nu^3}{c^2}\right)\frac{1}{e^{\frac{h\nu}{kT}} - 1}\,d\nu$$

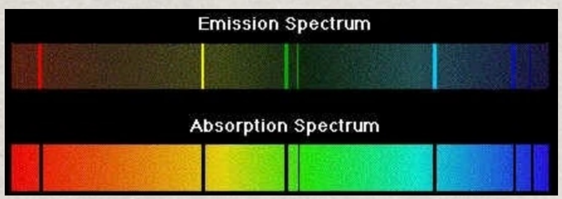


Albert Einstein: Photo-electric effect 1905 (1921)

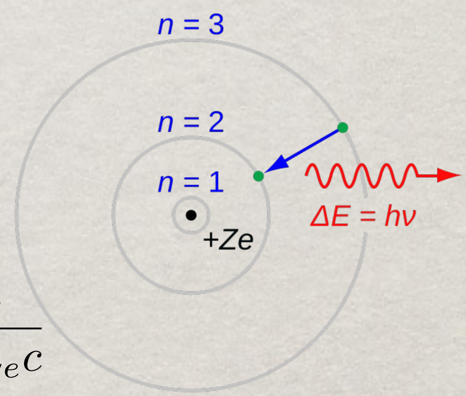


$$E_{\text{max}} = h\nu - W_0$$

Neils Bohr: Atomic model 1913 (1922)

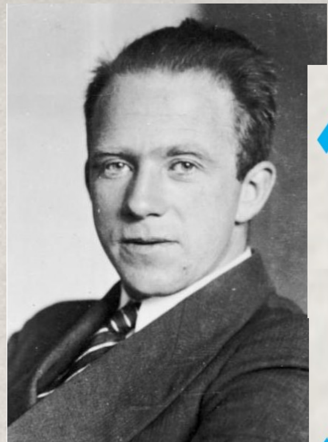


$$a_0 = \frac{\hbar}{\alpha m_e c}$$



Louis de Broglie: Matter wave 1924 (1929)

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$



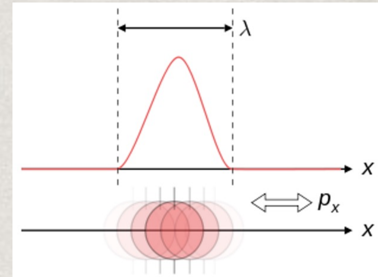
Werner Heisenberg:
Matrix mechanics 1925
(Born & Jordan, 1926)

$$\mathbf{PQ} - \mathbf{QP} = \frac{\hbar}{i}\mathbf{I} \qquad \frac{\partial \hat{O}(t)}{\partial t} = \frac{1}{i\hbar}[\hat{O}(t), \hat{H}]$$

Uncertainty principle 1927

$$\Delta x \Delta p \geq \hbar/2 \quad \Delta E \Delta t \geq \hbar/2$$

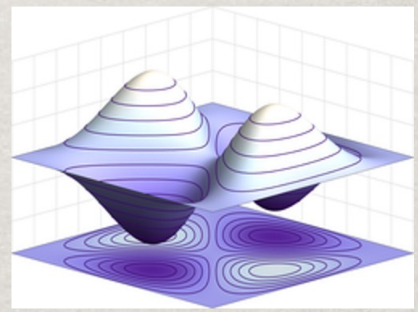
… …



(1932)

Erwin Schrödinger: Schrödinger Equation 1926

$$i\hbar \frac{d}{dt}|\Psi(t)\rangle = \hat{H}|\Psi(t)\rangle$$

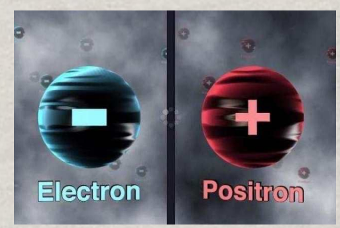


(1933)

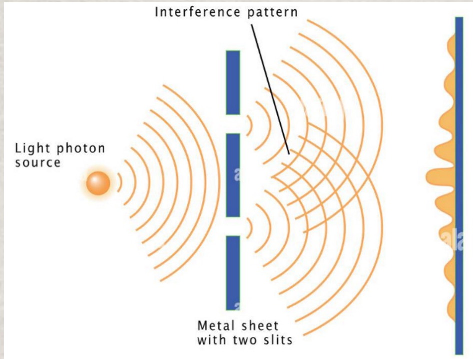
Paul Dirac: $\{F, G\} \Rightarrow \frac{1}{i\hbar}[\hat{F}, \hat{G}]$

Dirac relativistic Equation 1928

$$i\hbar \frac{\partial \psi(\mathbf{x}, t)}{\partial t} = \left(\frac{\hbar c}{i} \boldsymbol{\alpha} \cdot \boldsymbol{\nabla} + \beta m c^2 \right) \psi(\mathbf{x}, t)$$



Max Born: Wave function statistical interpretation 1926



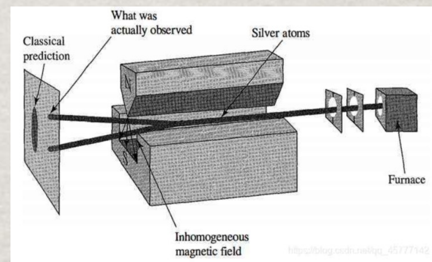
$$P = |\Psi|^2$$

(1954)

Wolfgang Pauli: Electron spin & exclusion principle 1925, Spin–statistics theorem 1940

(1945)

$$\psi(\mathbf{r}_a, \mathbf{r}_b) = [\psi_1(\mathbf{r}_a)\psi_2(\mathbf{r}_b) \pm \psi_1(\mathbf{r}_b)\psi_2(\mathbf{r}_a)]/\sqrt{2}$$

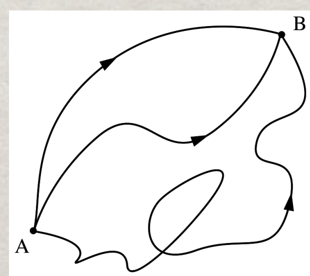


Richard Feynman: Path integral formulation 1948 & QED renormalization

(1965)

$$\langle F \rangle = \frac{\int \mathcal{D}\varphi F[\varphi] e^{iS[\varphi]}}{\int \mathcal{D}\varphi e^{iS[\varphi]}}$$

$$S(\phi) = \int d^4x \mathcal{L}(\phi, \dot{\phi})$$



Milestone Experiments Revealing Quantum Behavior

1. Blackbody Radiation (Planck, 1900)

- **Problem:** Classical physics couldn't explain why the radiation emitted by a blackbody diverged at short wavelengths (the "ultraviolet catastrophe").
- **Insight:** Max Planck proposed that energy is quantized and emitted in discrete packets (quanta) introducing the idea of **energy quanta** $E = h\nu$.

2. Photoelectric Effect (Einstein, 1905)

- **Problem:** Classical wave theory couldn't explain why light below a certain frequency doesn't eject electrons from a metal surface.
- **Insight:** Albert Einstein proposed that light is made of **photons** with quantized energy, supporting the **particle nature of light** and confirming Planck's quantum hypothesis.

3. Franck–Hertz Experiment (1914)

- **Problem:** Needed to test the quantized nature of atomic energy levels.
- **Insight:** Electrons gained/expended energy in discrete amounts, providing direct evidence for **quantized energy levels in atoms** (especially mercury atoms).

4. Compton Scattering (1923)

- **Problem:** Classical wave theory couldn't account for the scattering of X-rays by electrons.
- **Insight:** Arthur Compton demonstrated that photons carry momentum, confirming the **particle-like behavior of light** and supporting Einstein's photon model.

5. Stern–Gerlach Experiment (1922)

- **Problem:** Classical physics predicted a continuous range of outcomes for magnetic moment directions.
- **Insight:** Only discrete values of angular momentum (spin) were observed, showing **quantum spin quantization**.

6. Davisson–Germer Experiment (1927)

- **Problem:** Could electrons exhibit wave-like behavior?
- **Insight:** Electrons diffracted off a crystal lattice just like waves, confirming **de Broglie's hypothesis** that particles have **wave-particle duality**.

7. Double-Slit Experiment with Electrons (1927, further by Tonomura in 1980s)

- **Problem:** Could single particles interfere with themselves?
- **Insight:** Electrons sent one at a time through two slits still formed an interference pattern, showing **wave-particle duality** and **quantum superposition**.

8. Zeeman Effect (1896)

- **Problem:** Why do spectral lines split in a magnetic field?
- **Insight:** The splitting of spectral lines in a magnetic field hinted at **quantized angular momentum** and **magnetic properties of electrons**, helping develop quantum models of the atom.

9. Lamb Shift (1947)

- **Problem:** Slight differences in hydrogen energy levels were unexplained by Dirac's theory.
- **Insight:** Measured by Lamb and Retherford, this shift led to the development of **quantum electrodynamics (QED)** and revealed the role of the **quantum vacuum**.

10. Bell Test Experiments (1960s–1980s)

- **Problem:** Could hidden variables explain quantum entanglement?
- **Insight:** Experiments by Aspect and others confirmed that **quantum entanglement violates Bell's inequalities**, ruling out local hidden variables and confirming **nonlocality**.

"Not only is the Universe stranger than we think, it is stranger than we can think."

-- Werner Heisenberg

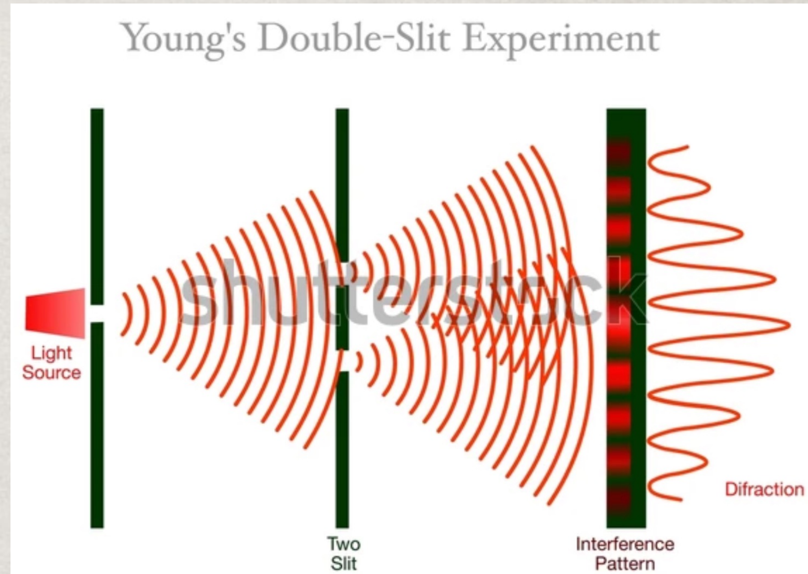
"Quantum mechanics describes nature as absurd from the point of view of common sense And yet it fully agrees with experiment. So I hope you can accept nature as She is - absurd."

-- Richard Feynman

Wave-Particle Duality

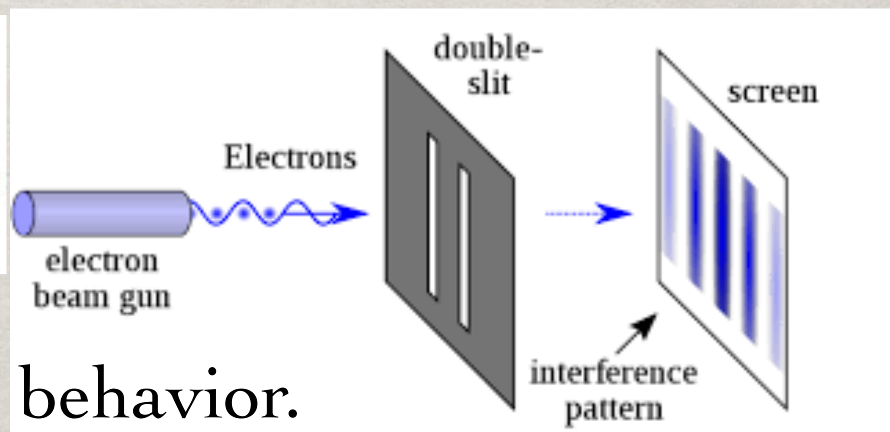
Light beams $\lambda \ll D$

Light waves $\lambda \sim d \sim 500$ nm



Electron beam

De Broglie wave $\lambda_D \sim d \sim 0.01$ nm



This can be a normal behavior.

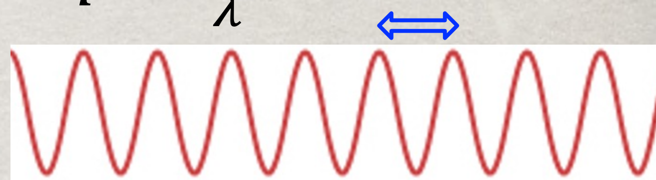
Uncertainty Principle $\Delta x \Delta p \geq \hbar/2$

"Thus, the more precisely the position is determined, the less precisely the momentum is known, and vice versa."

– W. Heisenberg

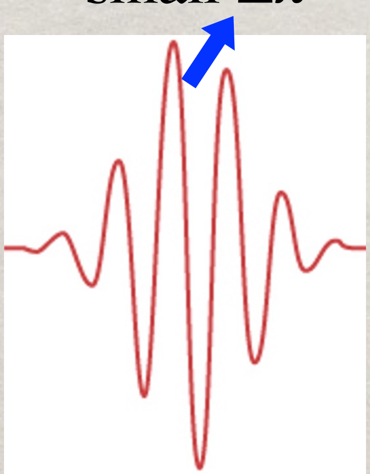
Based on the wave-particle duality:

- A plane wave have fixed $\boldsymbol{\lambda}$, thus definite $p = \frac{h}{\lambda}$, but undetermined location x



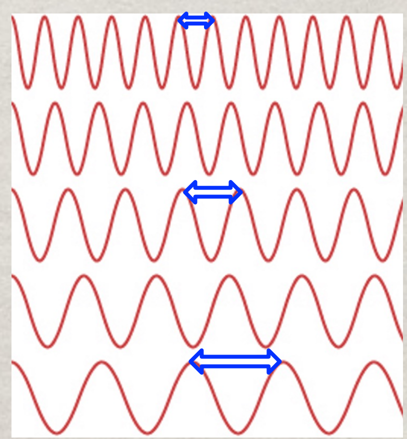
- A narrow wave packet has a small Δx, but with unconstrained all momenta p

small Δx

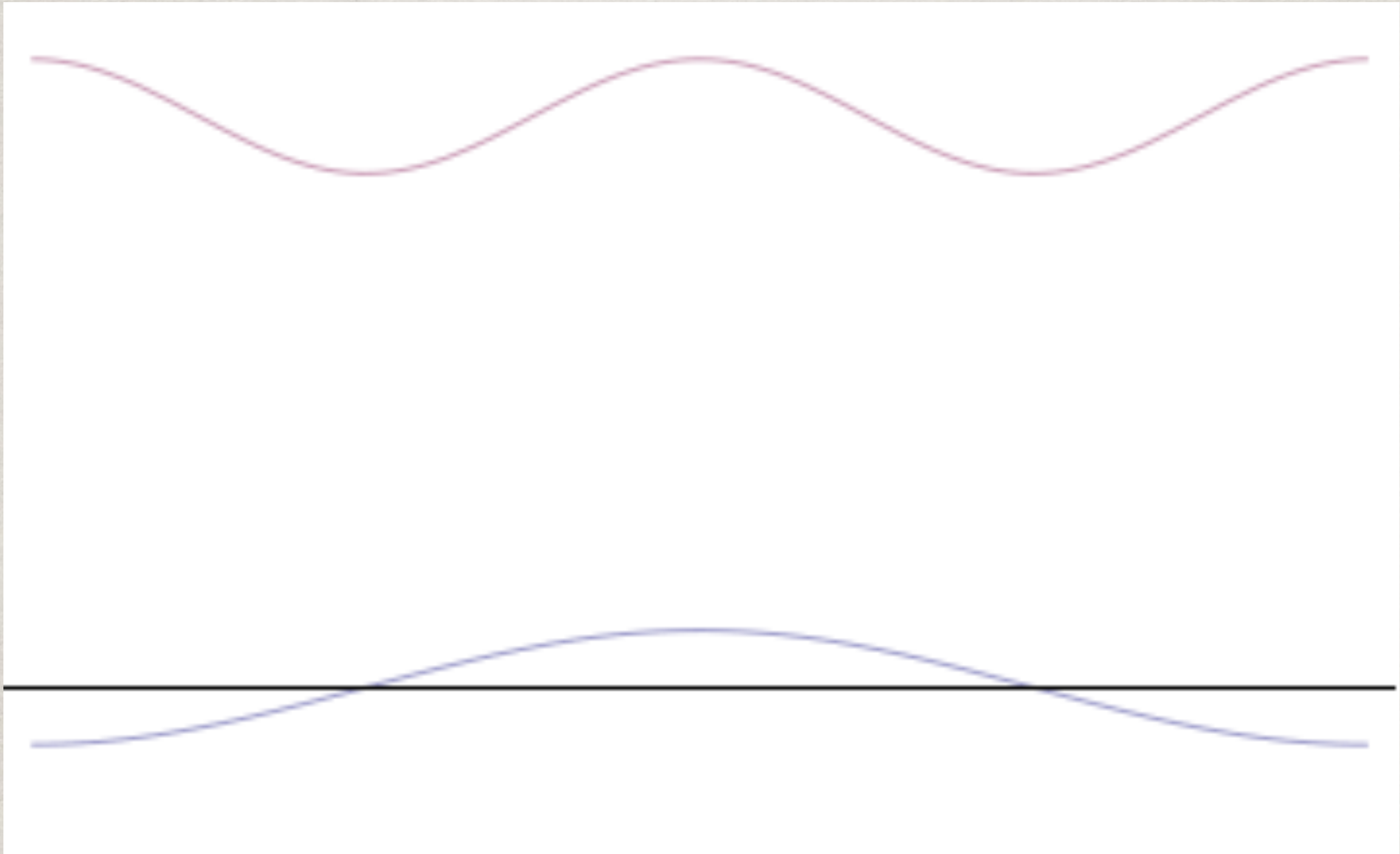


<−−>

many plane waves, large Δp

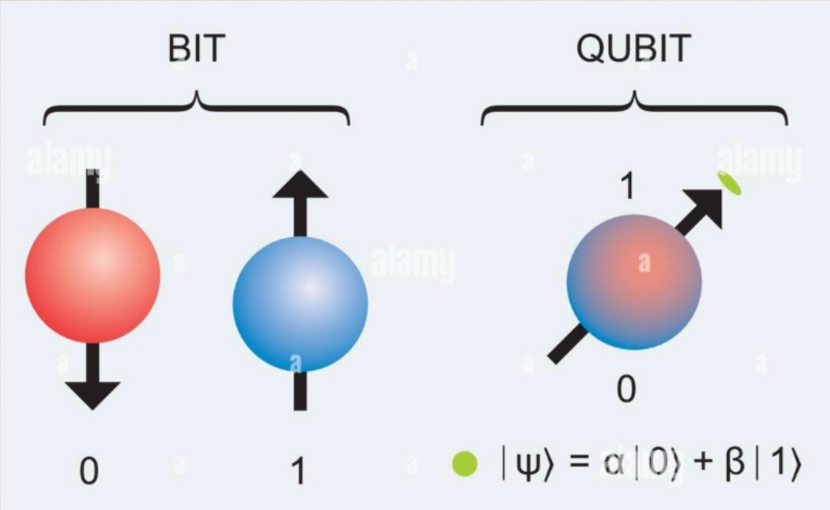


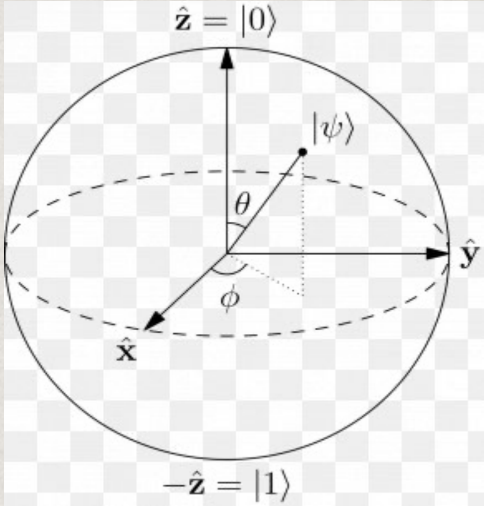
$$\Delta x \Delta p \geq \hbar/2$$



$$\delta(x-\alpha) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{ip(x-\alpha)}\, dp$$

Superposition of Quantum States





Classically: either or

Quantum: **AND**

Bloch sphere

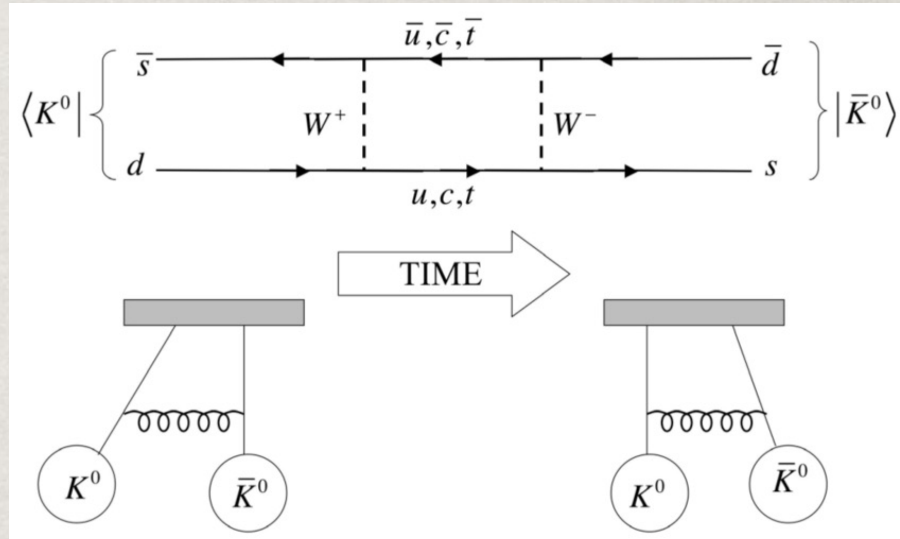
Bloch sphere solution: $\alpha = \cos\frac{\theta}{2}, \quad \beta = e^{i\phi}\sin\frac{\theta}{2}$

Oscillatory solution: $|\psi\rangle = \cos\theta \; e^{iE_0}|0\rangle + \sin\theta \; e^{iE_1}|1\rangle$

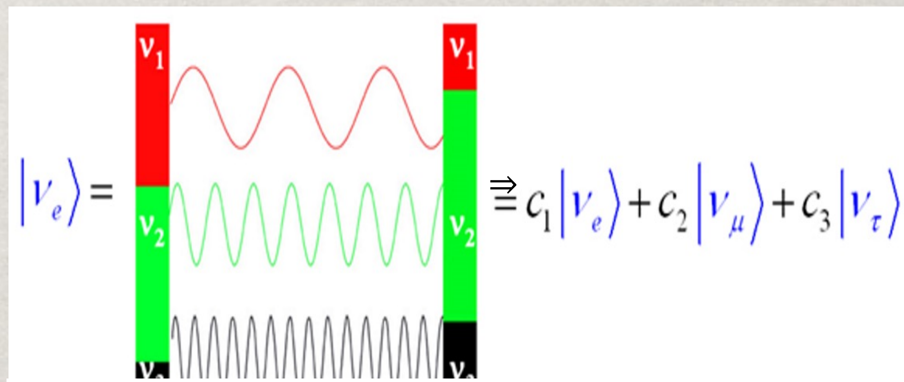
Qubits → larger amount of information, foundation for quantum information / computation!

Superposition & Oscillation of States

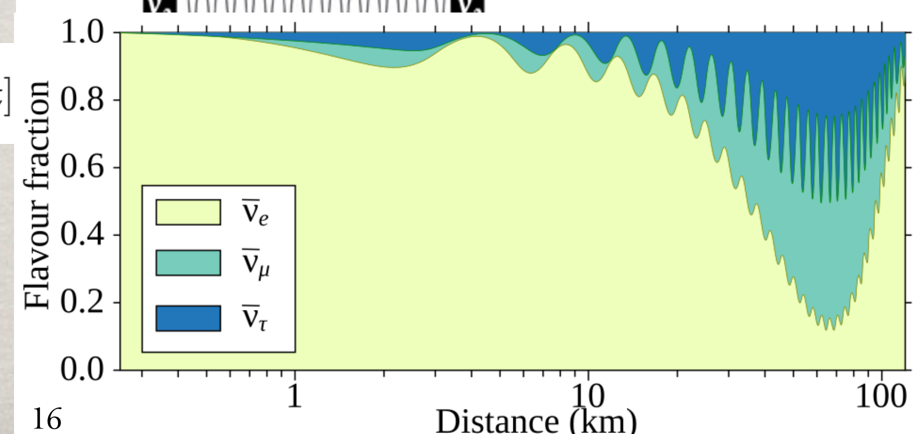
- **Neutral meson system**
  "Flavor" physics:
  quark flavor mixing; heavy quark masses; CP violation …



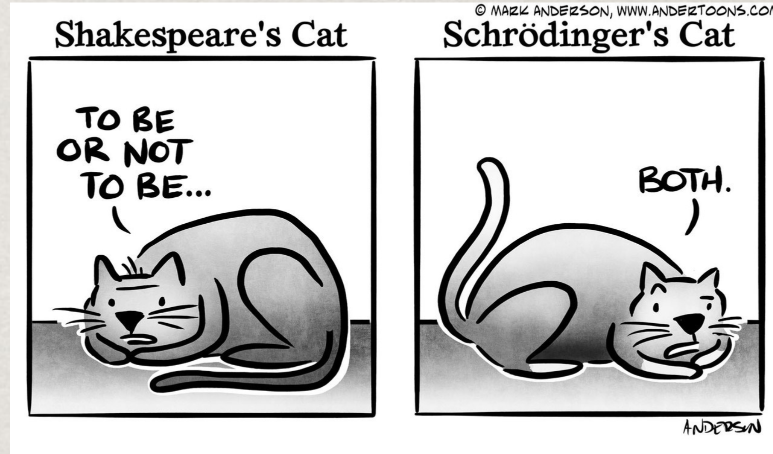
- **Neutrino mixing:**
  lepton flavor mixing; neutrino masses; CP violation …



$$P_{\nu_e \to \nu_\mu}(t) = |\langle \nu_\mu | \nu_e(t) \rangle|^2 = \frac{1}{2} \sin^2 2\theta \cdot [1 - \cos(E_1 - E_2)t]$$



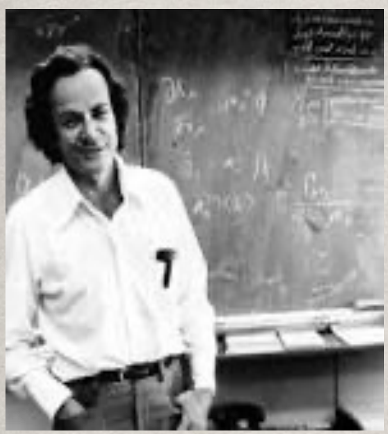
Schrödinger's cat: Life & Death Superposition



Copenhagen interpretation:

Schrödinger equation ⇒ wave function evolves (√)

Observation ⇒ wave function collapses by measurements (!?)



"If you think you understand quantum mechanics, you don't understand quantum mechanics."

"… It is my task to convince you not to turn away because you don't understand it. You see my physics students don't understand it, that is because I don't understand it. Nobody does."

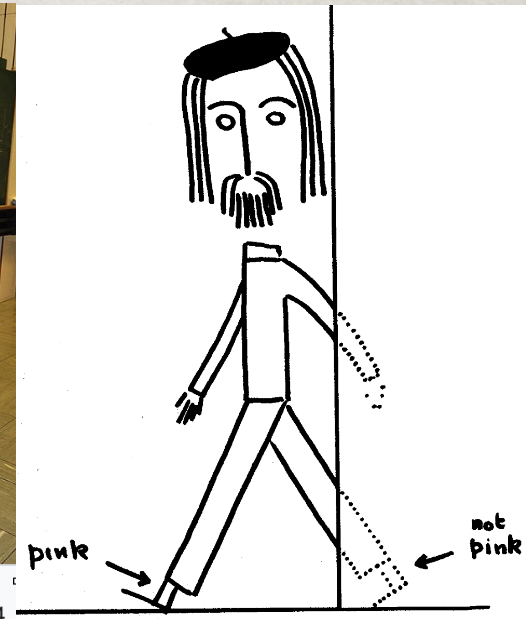
Quantum Entanglement

Classical correlation

Bertlmann's socks:

pink or non-pink

David Mermin und Reinhold Bertlmann zeigen ihre Socken, 2014



Quantum correlation/ Entanglement

A spin-1/2 state: $\pm\frac{1}{2}$

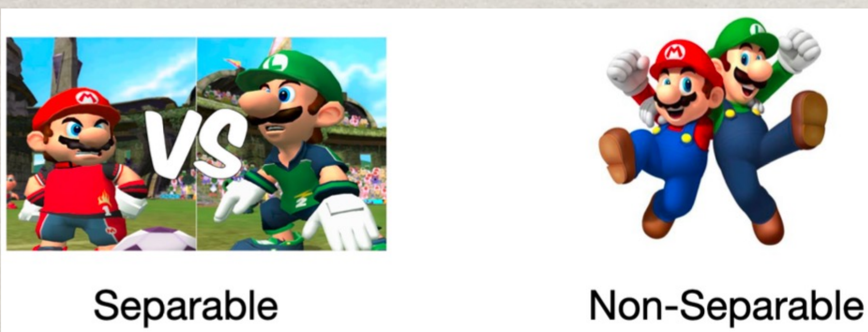
Not determined in 2 directions!

For a bipartite system, *i.e.*, $\frac{1}{2}\otimes\frac{1}{2} = 1\oplus 0$:

Singlet: $|0,0\rangle = \frac{1}{\sqrt{2}}(\uparrow\downarrow - \downarrow\uparrow)$

Triplet:
$$\begin{aligned} |1,1\rangle &= \uparrow\uparrow \\ |1,0\rangle &= \frac{1}{\sqrt{2}}(\uparrow\downarrow + \downarrow\uparrow) \\ |1,-1\rangle &= \downarrow\downarrow \end{aligned}$$

Entangled



Quantum entanglement

→ sub-systems inseparable:

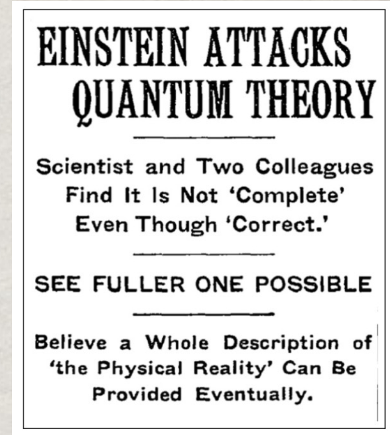
Measurement 1 selects 2 !

Einstein-Podolsky-Rosen Paradox (Phys. Rev. 1935)

"Can quantum-mechanical description of physical reality be considered complete?"

"God doesn't play dice with the universe" – A. Einstein

→ **Local Hidden Variable Theory (LHVT)**



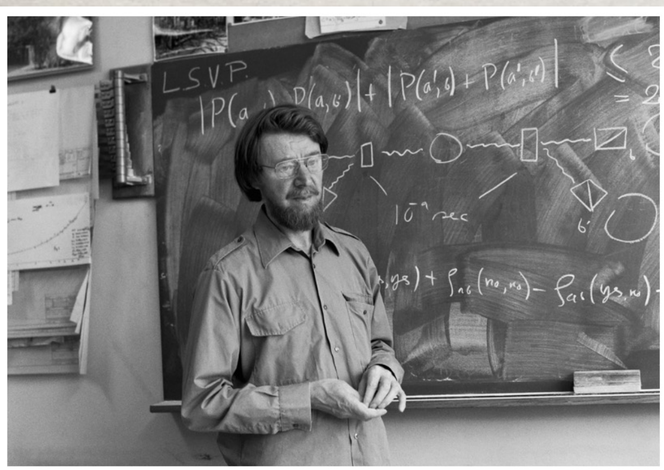
EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

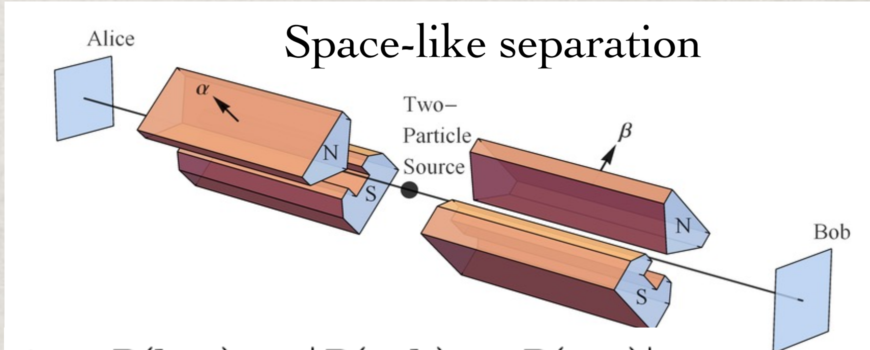
SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.

John S. Bell's Inequality



"On the Einstein-Podolsky-Rosen paradox" (1964)



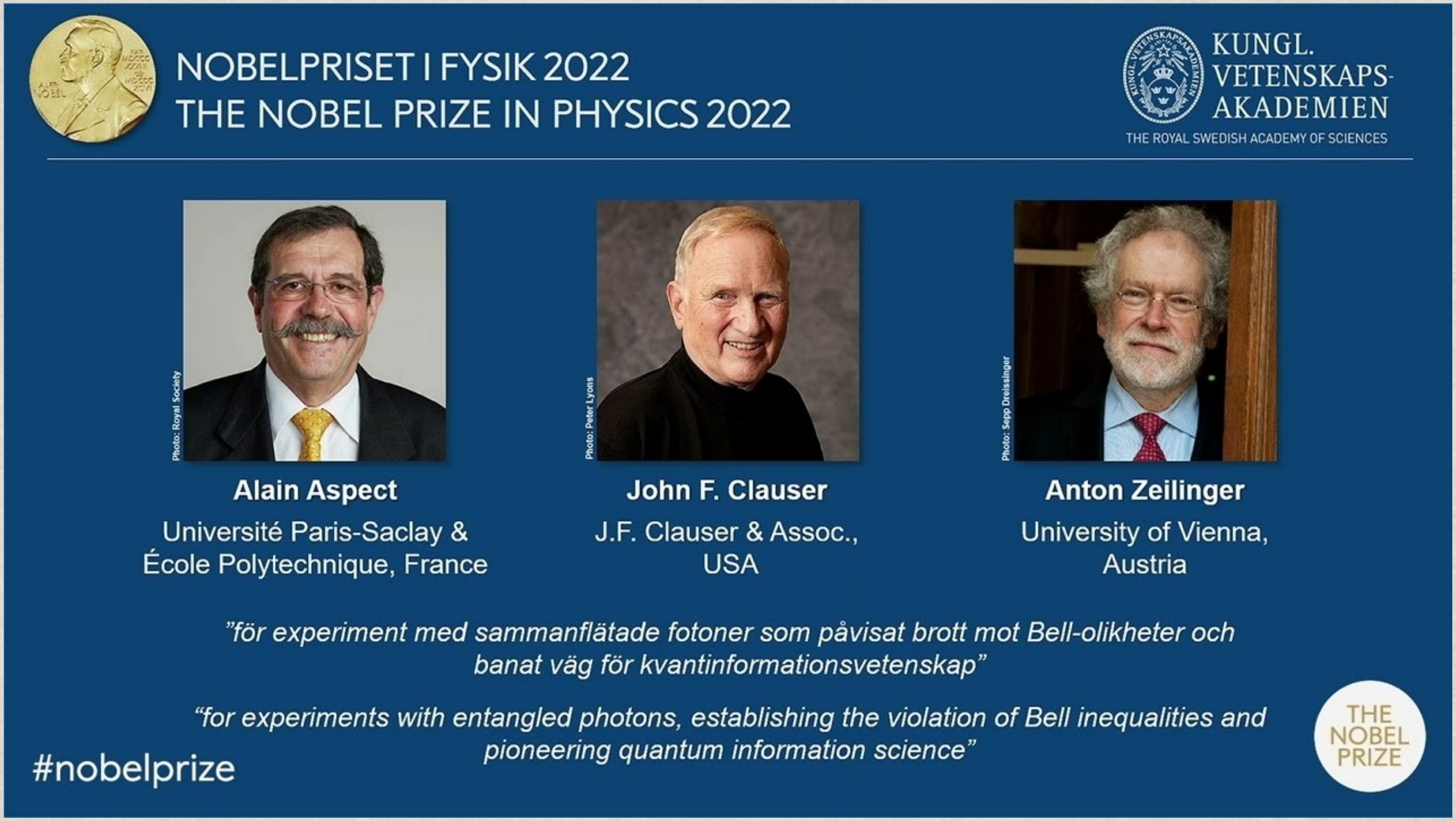
$$1 + P(\mathbf{b}, \mathbf{c}) \geq |P(\mathbf{a}, \mathbf{b}) - P(\mathbf{a}, \mathbf{c})|.$$

QM Non-Communitivity is the key:

EPR's LHVT must satisfy Bell's Inequality,

but CAN BE violated by QM measurements.

→ **"Quantum Information"**



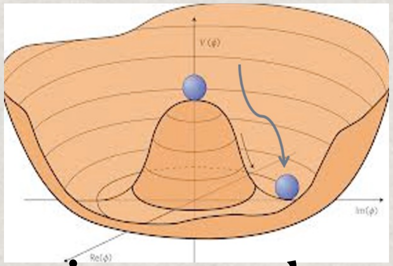
The 2022 Nobel Prize in Physics was awarded to Alain Aspect, John Clauser, and Anton Zeilinger for their groundbreaking experiments in quantum mechanics, specifically for their work with entangled quantum states. These experiments established the violation of Bell inequalities and pioneered quantum information science.

Macroscopic Quantum Phenomena

(1972)

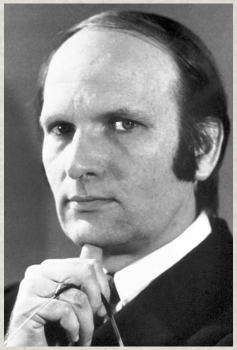
- Superconductivity:

- Cooper pairs formation (e^-e^-) and condense to a new ground state



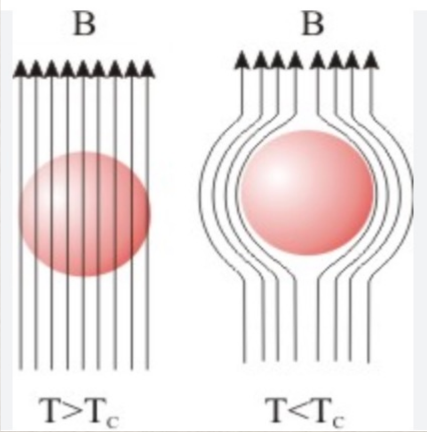
John Bardeen

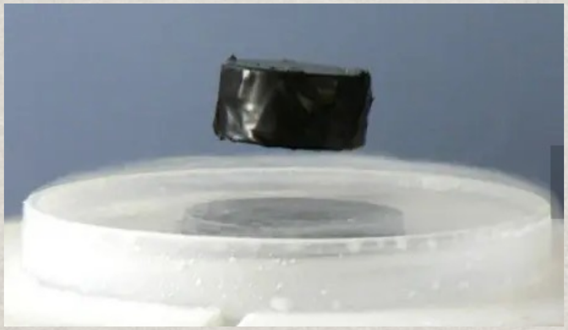
Leon Cooper



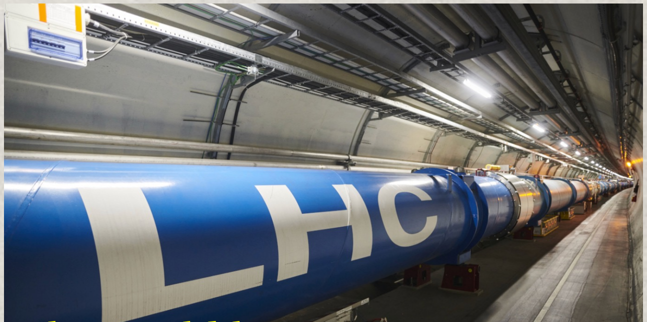
Robert Schrieffer

- Zero electric resistance!
- Photons acquire a mass via the Higgs mechanism and stop propagating in a super conductor.





Meissner effect



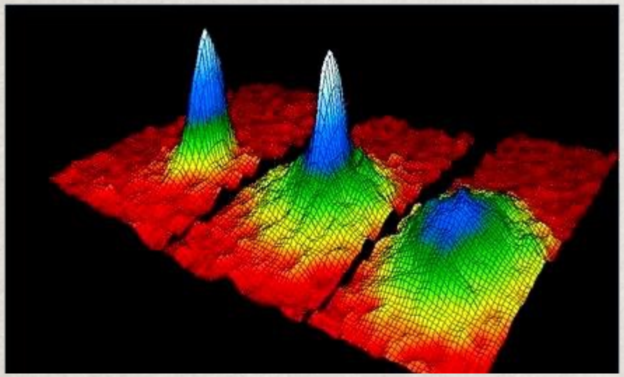
The world largest SC magnets
(Macro-quantum effects)

Macroscopic Quantum Phenomena

- Bose-Einstein condensation

(2001)

- All bosons occupy in a new state below T_c



Velocity distribution

Eric Cornell

Carl Wieman

Wolfgang Ketterle

- Superfluidity & Superconductivity

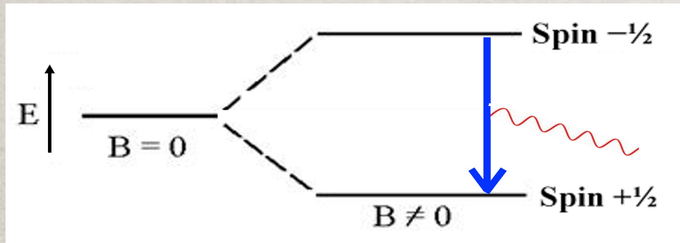
Bosons condensate

→ high density within its de Broglie wavelength: Collective wave behavior of “particles”

→ e.g. axion-like wave-like cold dark matter!

Quantum Technology in the Real World

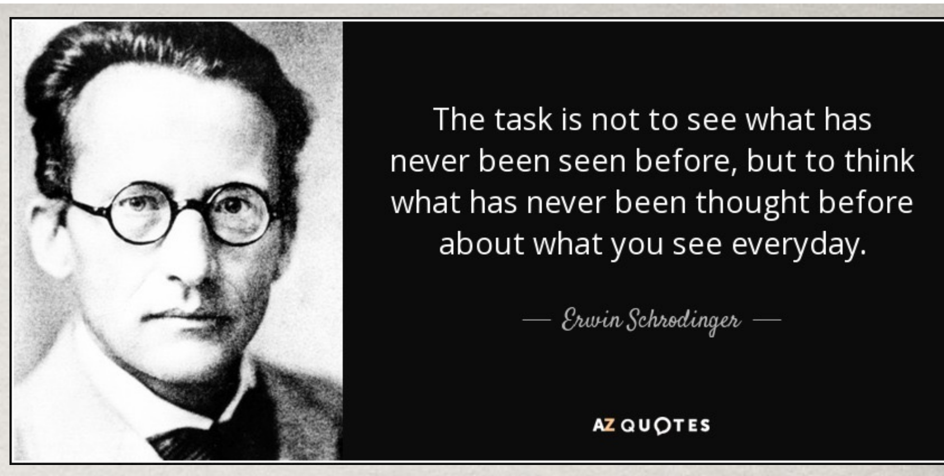
Spin $\frac{1}{2}$ system in magnetic field:



$$\Delta E = \gamma \hbar B$$

gyromagnetic ratio

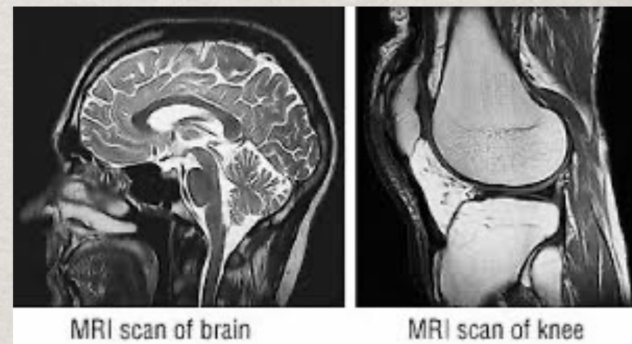
$$h\nu = \Delta E$$



Magnetic Resonance Imaging (MRI):

Applying position dependent $B(x)$

⇒ location of hydrogen atoms

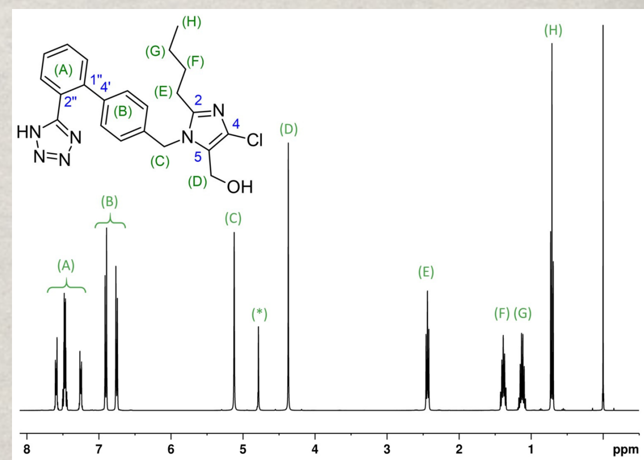


MRI scan of brain MRI scan of knee

Nuclear Magnetic Resonance (NMR):

Measuring the frequency of radiation

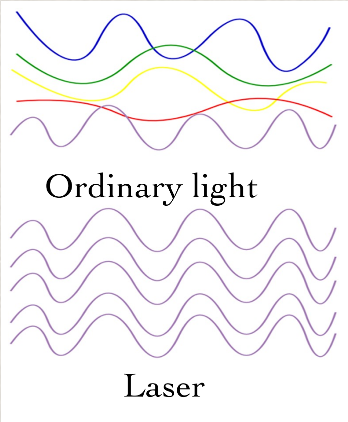
⇒ characteristic types of atoms

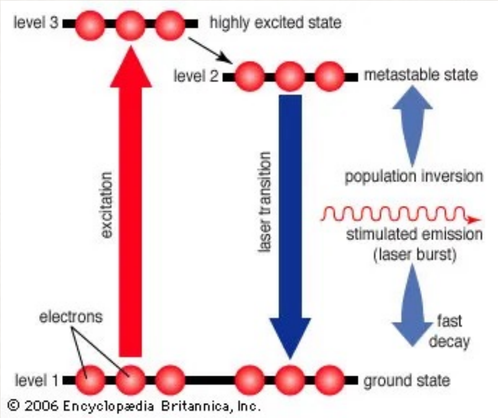


Quantum Technology in the Real World

Laser:

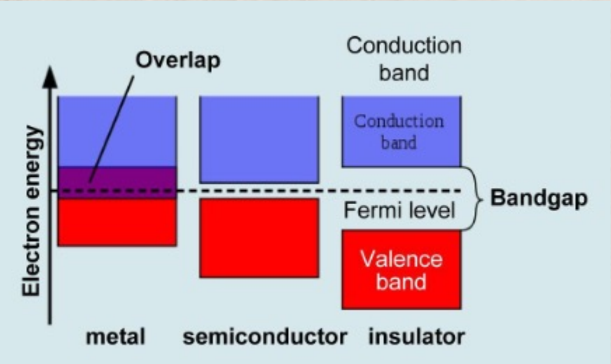
Monochromatic
Coherence
Directionality





$$h\nu = E_2 - E_1$$

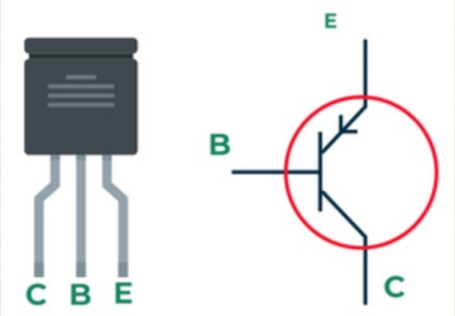
Semiconductor / Transistor:

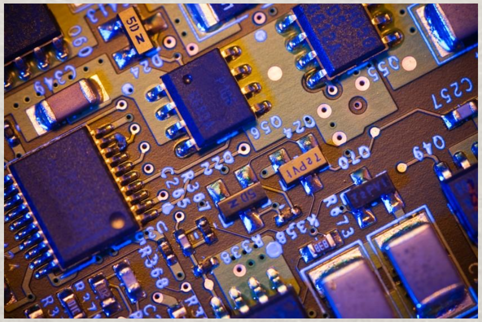


intermediate energy band:

- switch between conductor and insulator
- ideal for controlling current!

QM EVERYWHERE!





Smartphones and Laptops
Power Control, Displays
Wireless Communication
(5G, Wi-Fi)

"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical."

-- Richard Feynman

The Second Quantum Revolution: Quantum Information Science

- New quantum technologies
- Quantum sensors
- Quantum computing
- Quantum communication

Quantum State & Quantum Tomography

For a state vector $|\phi_i\rangle$

Density matrix

a state

$$\rho = \sum_i n_i |\phi_i\rangle \langle\phi_i|$$

an observable

$$\langle\mathcal{O}\rangle = \mathrm{Tr}(\mathcal{O}\rho)$$

For a **pure state**: $n_i = 1$; for a **mixed state**: $\boldsymbol{\Sigma}_i\, n_i = 1$.

For a **single qubit** (*i.e.*, a doublet of spin, iso-spin etc.):

$$\rho = \frac{1}{2}\left(\mathbb{I}_2 + \sum_i B_i \sigma_i\right)$$

For a **bipartite system** (*i.e.*, ½⊗½)

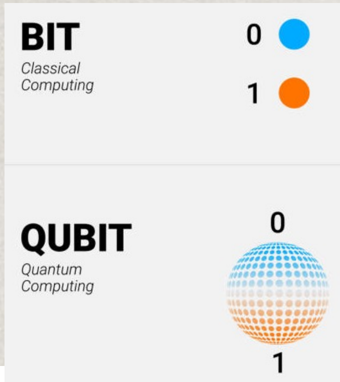
$$\rho = \frac{1}{4}\left(\mathbb{I}_4 + \sum_i \left(B_i^{\mathcal{A}}\left(\sigma_i \otimes \mathbb{I}_2\right) + B_i^{\mathcal{B}}\left(\mathbb{I}_2 \otimes \sigma_i\right)\right) + \sum_{i,j} C_{ij}\left(\sigma_i \otimes \sigma_j\right)\right)$$

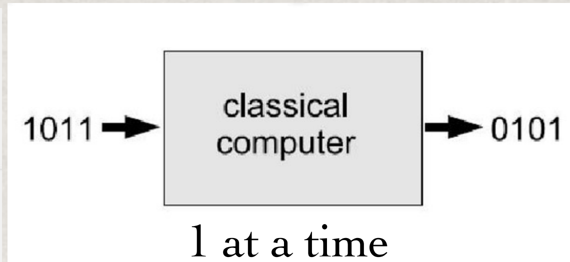
$B_i^{A,B}$ the polarizations, C_{ij} the spin-correlation matrix.

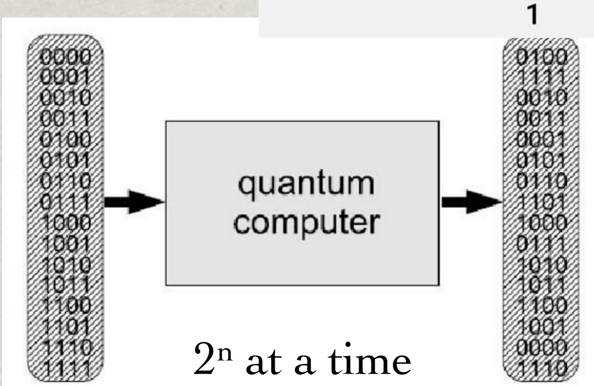
The 15 coefficients for the bipartite →

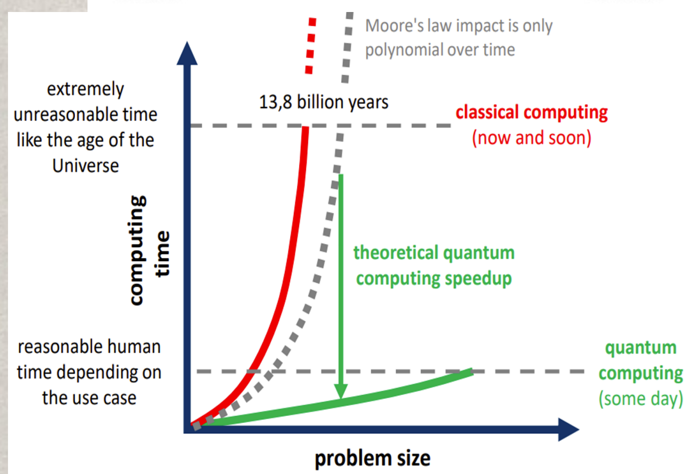
Quantum Tomography, which encodes the full QI.

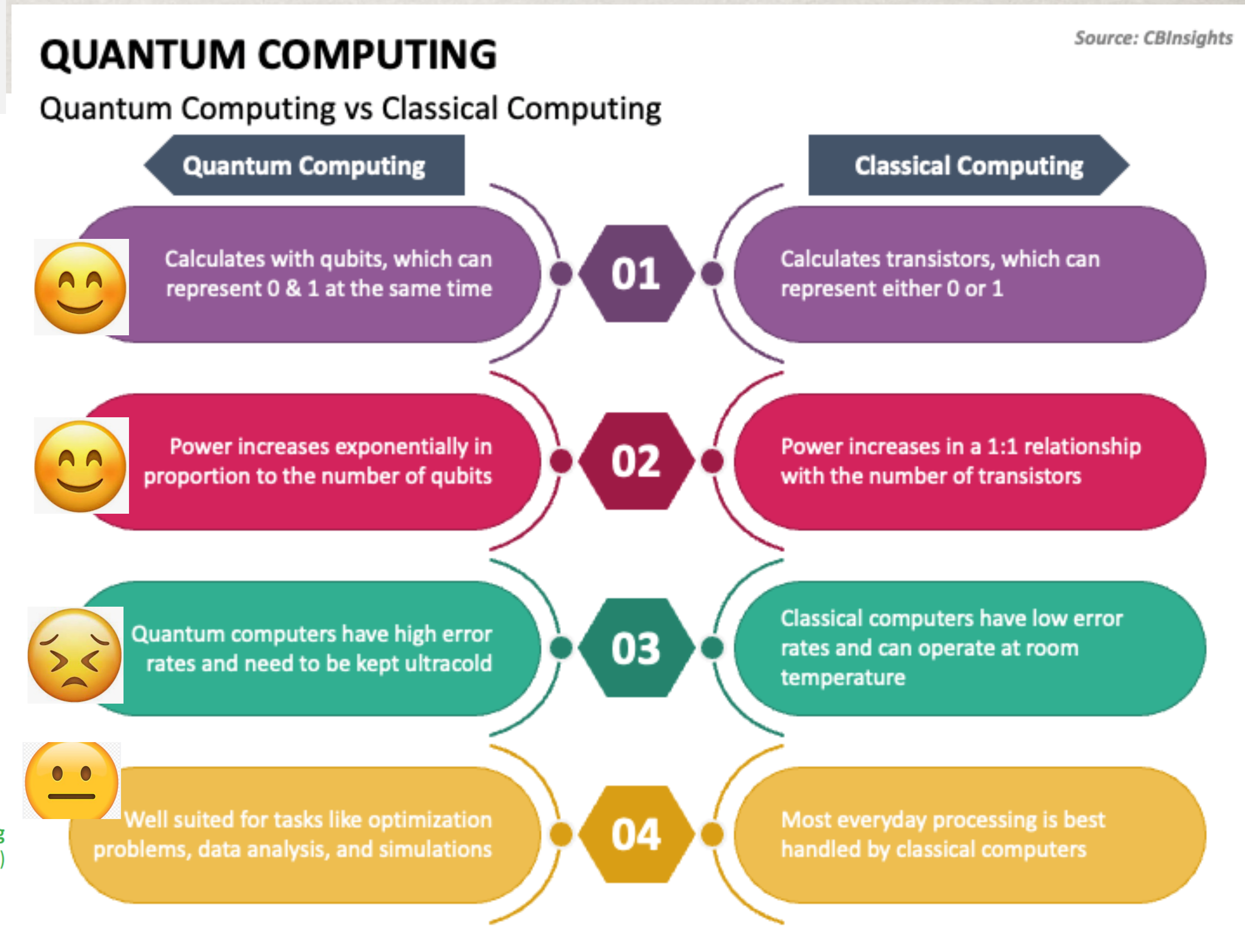
Quantum Computing with Qubits











The second quantum revolution is happening …

World at High Energies: Relativistic Quantum Mechanics

Special Relativity:

① Lorentz transformation:

$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad t' = \frac{t - \frac{vx}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$y' = y$$

$$z' = z$$

$\Longrightarrow$

Quantum Mechanics:

Lorentz invariant equation:

Spin-0: Klein–Gordon equation

$$\left(-\frac{1}{c^2}\frac{\partial^2}{\partial t^2} + \nabla^2\right)\phi = \frac{m^2c^2}{\hbar^2}\phi$$

Spin-1/2: Dirac equation

$$(i\hbar\gamma^\mu\partial_\mu - mc)\psi = 0$$

② Mass–energy equivalence:

$$E = mc^2$$

$\Longrightarrow$ Particle creation and annihilation

The second quantization:

Creation & annihilation operators $\boxed{a_{\mathbf{p}}}e^{-i\omega_{\mathbf{p}}t + i\mathbf{p}\cdot\mathbf{x}} + \boxed{a^*_{\mathbf{p}}}e^{i\omega_{\mathbf{p}}t - i\mathbf{p}\cdot\mathbf{x}}$

Bosons: $[a_\alpha, a^\dagger_\beta] = \delta_{\alpha,\beta}, \quad [a_\alpha, a_\beta] = [a^\dagger_\alpha, a^\dagger_\beta] = 0$

Fermions: $\{c_\alpha, c^\dagger_\beta\} = \delta_{\alpha,\beta}, \quad \{c_\alpha, c_\beta\} = \{c^\dagger_\alpha, c^\dagger_\beta\} = 0$

Particle number & energy operators

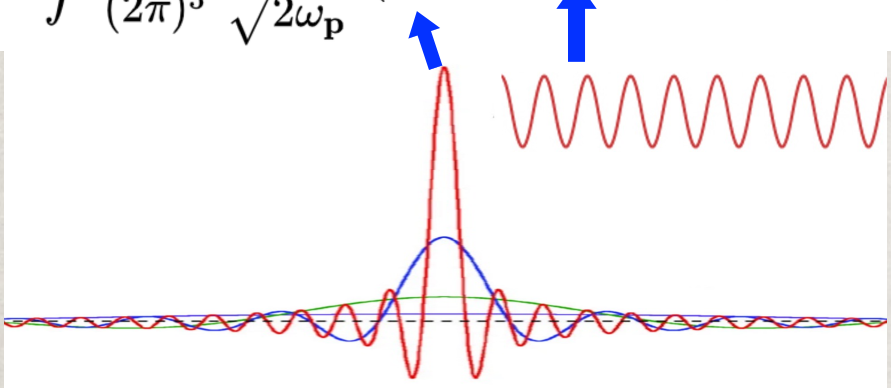
$$\hat{N}_p = a^\dagger_p a_p \qquad \hat{H} = (\hat{N}_p + \frac{1}{2})\hbar\omega$$

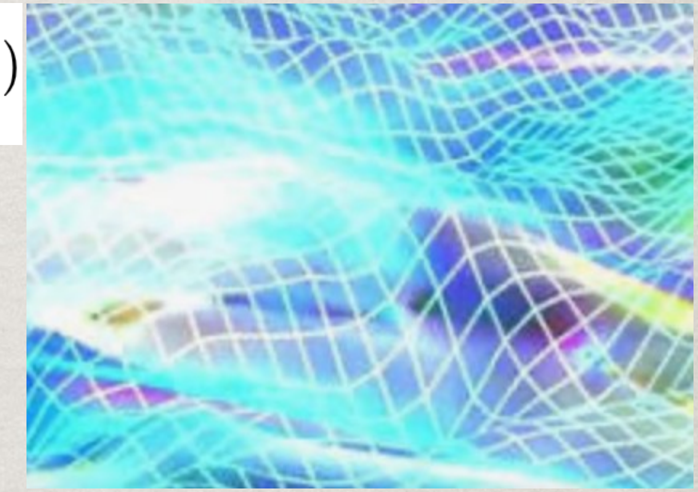
The state is a quantum field

Quantum Fields

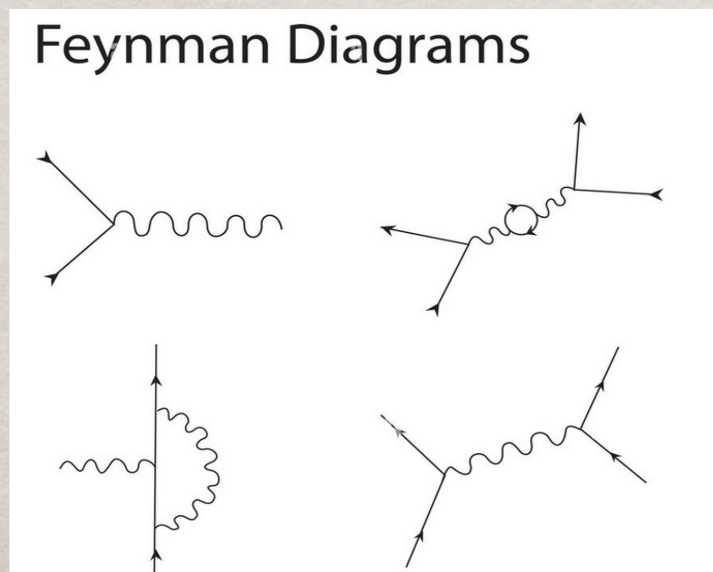
Field operators and the Lagrangian of fields:

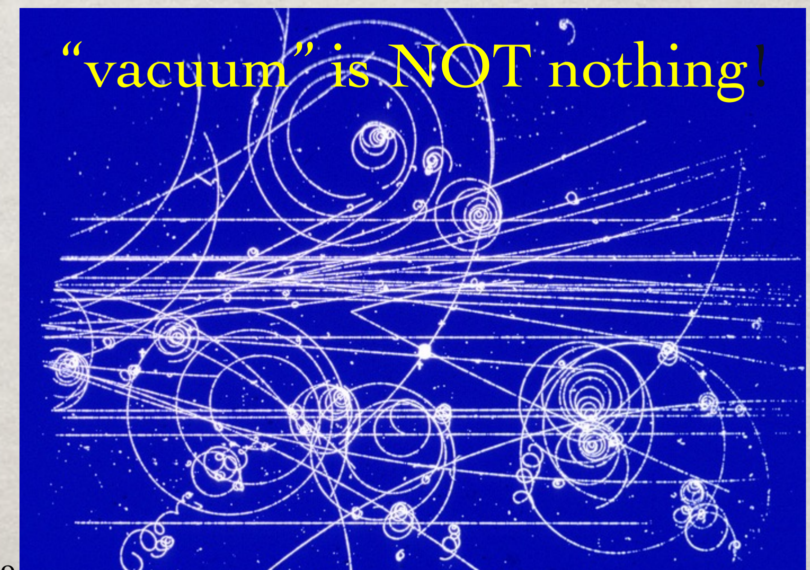
$$\phi(\mathbf{x},t) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\sqrt{2\omega_{\mathbf{p}}}} \left(a_{\mathbf{p}} e^{-i\omega_{\mathbf{p}}t + i\mathbf{p}\cdot\mathbf{x}} + a_{\mathbf{p}}^* e^{i\omega_{\mathbf{p}}t - i\mathbf{p}\cdot\mathbf{x}} \right)$$



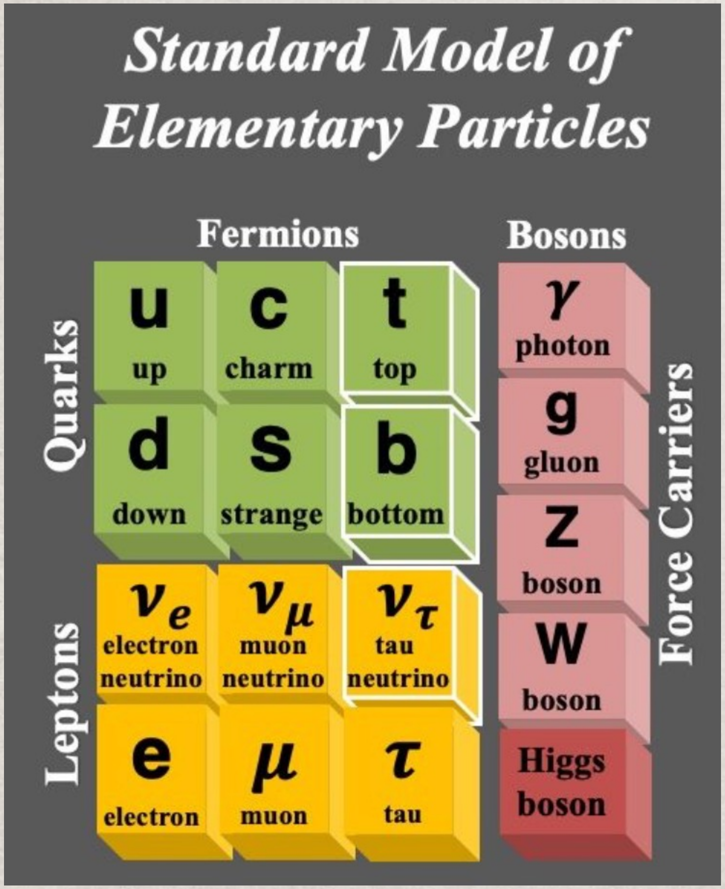


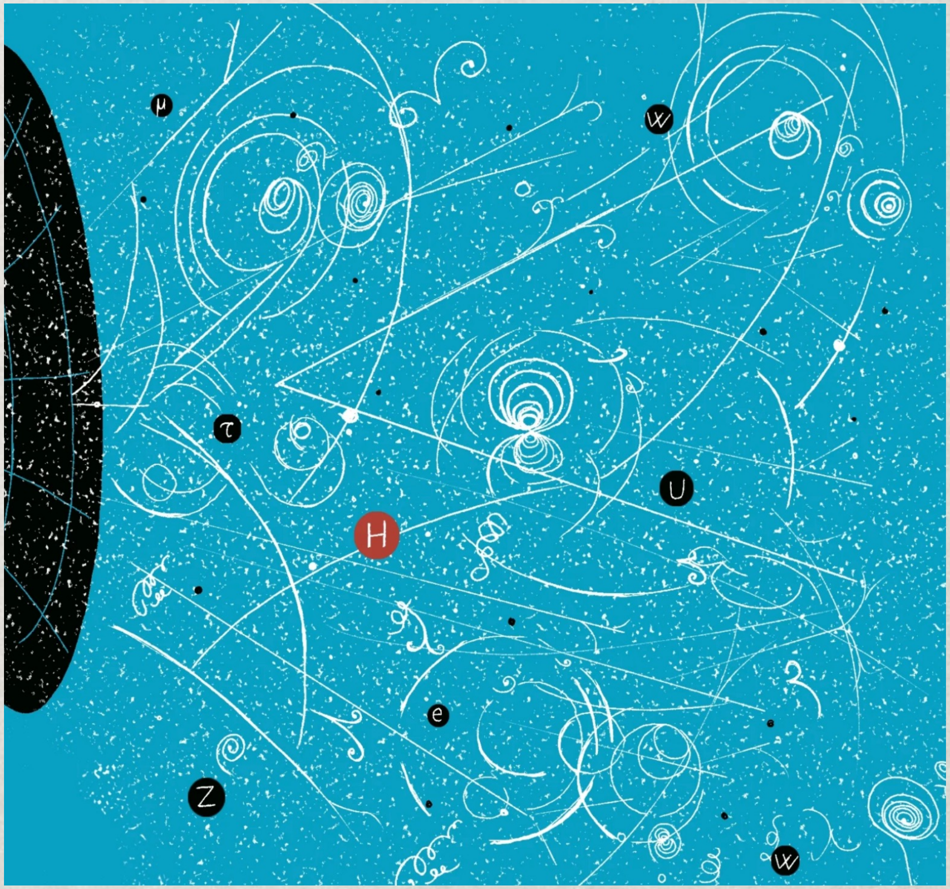
$$\langle x_f, t_f | x_i, t_i \rangle = \int \mathcal{D}x(t) e^{\frac{i}{\hbar}\int d^4x \mathcal{L}(\phi,\dot{\phi})}, \quad \mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4 ...$$





Elementary Particles as Fundamental Quanta:



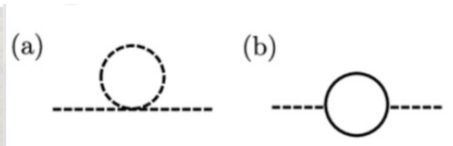


Classified by spin and mass,
plus internal (gauge) charges, flavor, CP ...

Quantum Probe to Shorter Distances

In interacting fields, quantum fluctuations:

$$|n(\lambda)\rangle = \left|n^{(0)}\right\rangle + \lambda \sum_{k\neq n} \left|k^{(0)}\right\rangle \frac{\left\langle k^{(0)}\middle| V \middle|n^{(0)}\right\rangle}{E_n^{(0)} - E_k^{(0)}} + \lambda^2 \sum_{k\neq n}\sum_{\ell\neq n} \left|k^{(0)}\right\rangle \frac{\left\langle k^{(0)}\middle| V \middle|\ell^{(0)}\right\rangle \left\langle \ell^{(0)}\middle| V \middle|n^{(0)}\right\rangle}{\left(E_n^{(0)} - E_k^{(0)}\right)\left(E_n^{(0)} - E_\ell^{(0)}\right)}$$



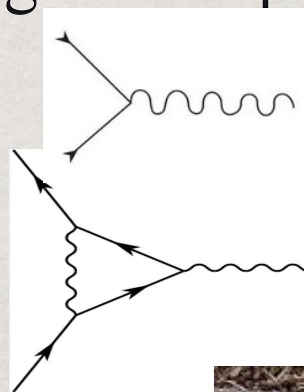
$$\int^{\Lambda} d^4p \, \frac{M_{ij}(p)}{D(p)} \qquad \int^{\Lambda}\int^{\Lambda} d^4p_1 d^4p_2 \, \frac{M_{ij}(p_1, p_2)}{D(p_1, p_2)}$$

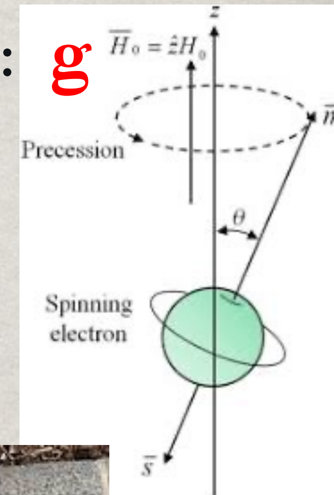
Quantum Electro-Dynamics on Trial

Dirac's relativistic quantum mechanics → QED

Feynman/Schwinger/Tomonaga ➔ Renormalization

Best example: Anomalous magnetic dipole moment: **g**





Dirac equation 1928: g = 2

Schwinger's quantum correction in QED in 1948:

$$(g\text{-}2)/2 = a_e(\text{Schwinger}) \approx \frac{\alpha}{2\pi} \approx 0.0011614$$

$$a_e^{theo} = 0.001159652181643(763)$$

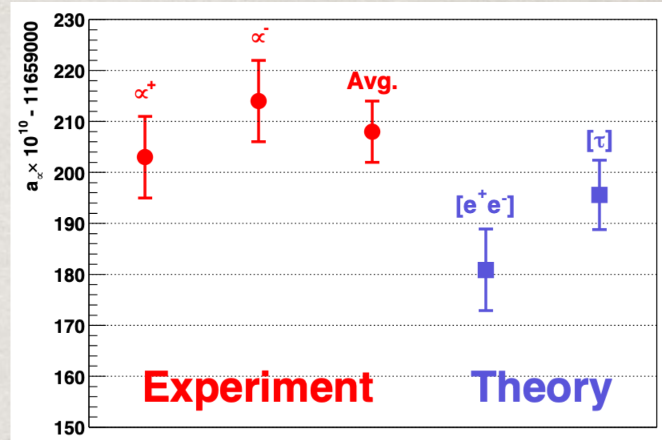
$$a_e^{exp} = 0.00115965218073(28)$$

Up to ~ 6-loops in QED → 10^{-10}

THE most accurate **quantum theory** in science!

The Standard Model on Trial

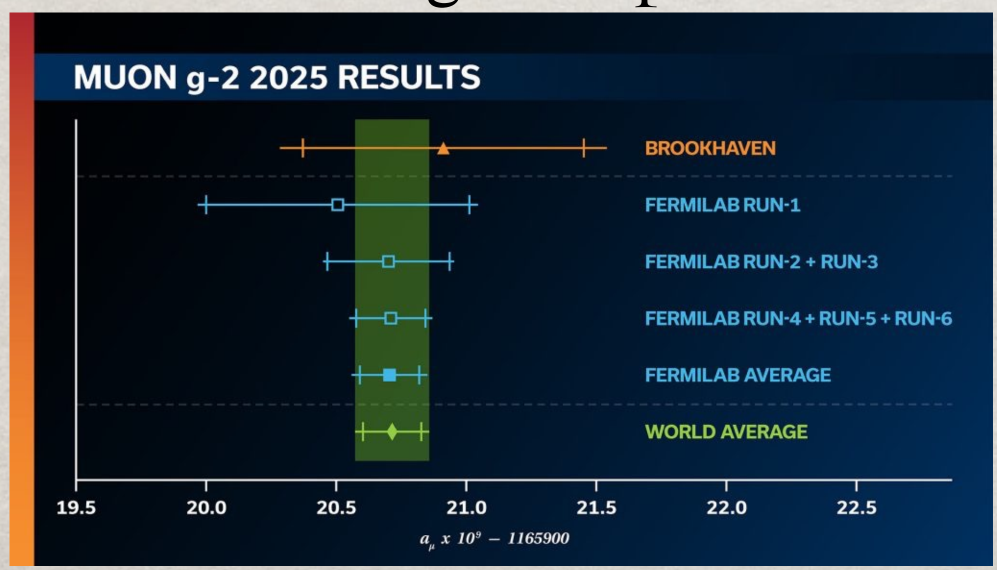
The Brookhaven Muon g-2 experiment

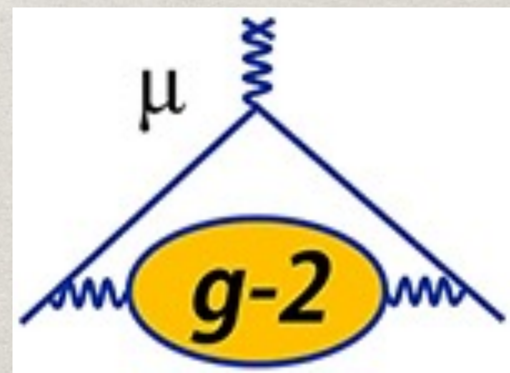


~ 0.54×10^{-6}! Potentially sensitive to BSM new physics!

Quantum probe: $\Delta p > 100 \text{ GeV} \Rightarrow \Delta x < 10^{-18} \text{ m}$

Fermilab Muon g-2 Experiment: E989

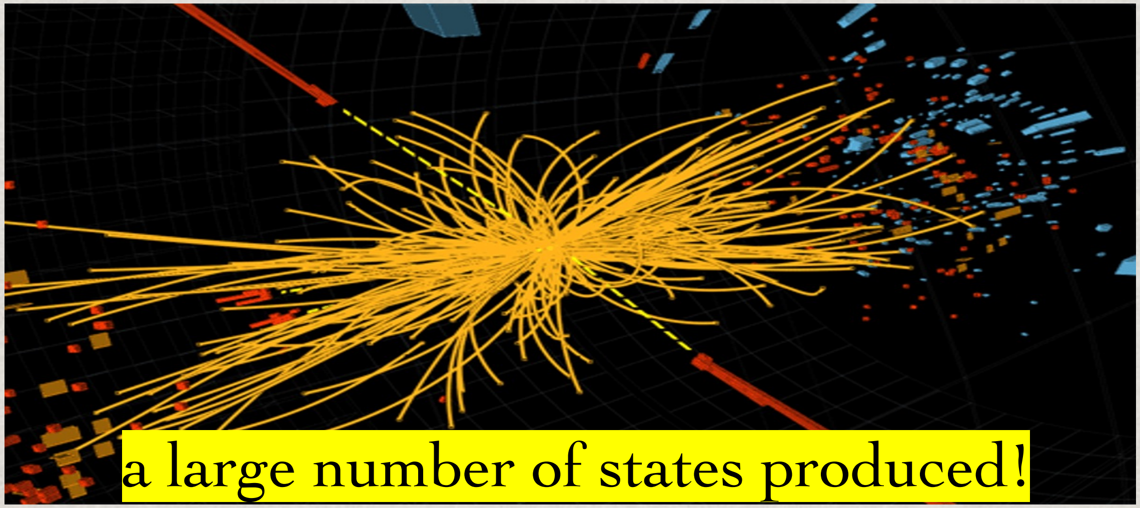




error @ 122 ppb

Truly triumphant!

Quantum Tomography @ Colliders



- Low energy photon experiment

Alice $\xleftarrow{\ \gamma\ }$ source $\xrightarrow{\ \gamma\ }$ Bob

- At LHC, treat the spin of each particle as a qubit

 $\xleftarrow{\ t\ }$ collision $\xrightarrow{\ \bar{t}\ }$ 

Potentially rich quantum information!

CERN press release on Sept. 19, 2024

nature

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > articles > article

Article | Open access | Published: 18 September 2024

Observation of quantum entanglement with top quarks at the ATLAS detector

The ATLAS Collaboration

Nature **633**, 542–547 (2024) | Cite this article

75k Accesses | **11** Citations | **485** Altmetric | Metrics

LHC experiments at CERN observe quantum entanglement at the highest energy yet

The results open up a new perspective on the complex world of quantum physics

18 SEPTEMBER, 2024

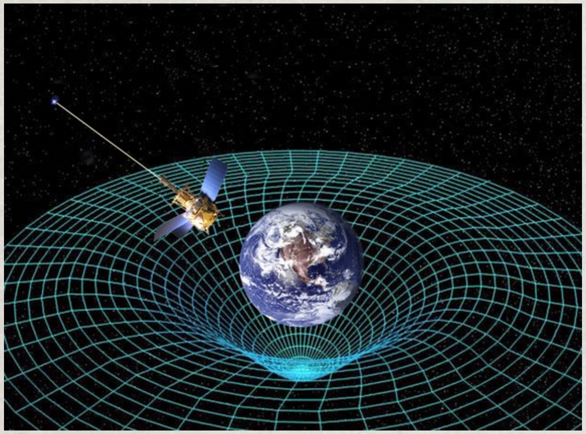
Artist's impression of a quantum-entangled pair of top quarks. (Image: CERN)

Open an avenue for Quantum Information in HEP!

When QM Meets GR

General Relativity: Dynamic space-time

Einstein equation (1915) $$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}T_{\mu\nu}$$



"Spacetime tells matter how to move; matter tells spacetime how to curve."

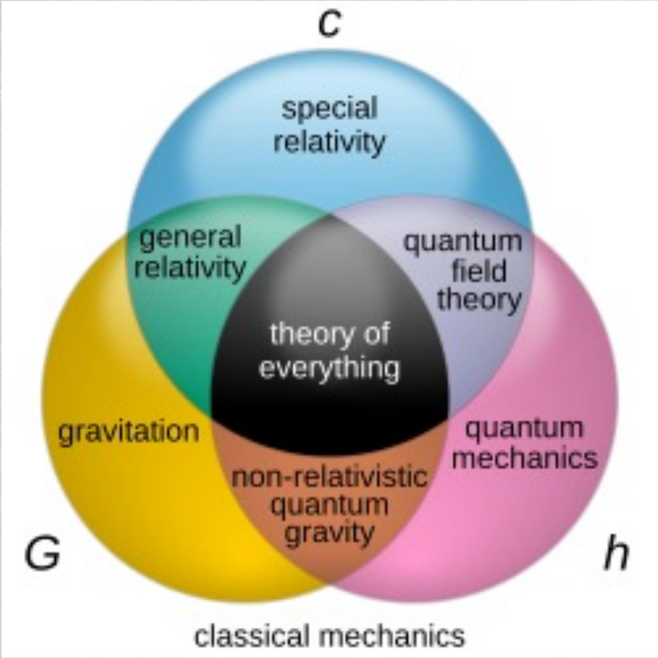
-- John Wheeler

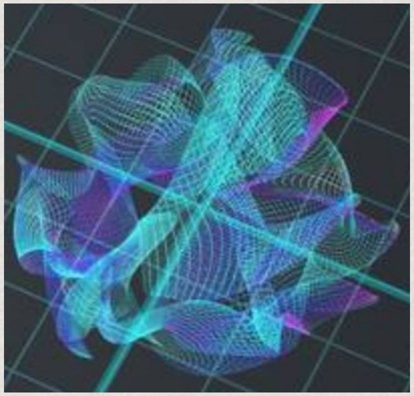
Near the Planck scale: $l_P = \sqrt{\frac{\hbar G}{c^3}} = 1.6\times10^{-35}\mathrm{m}$

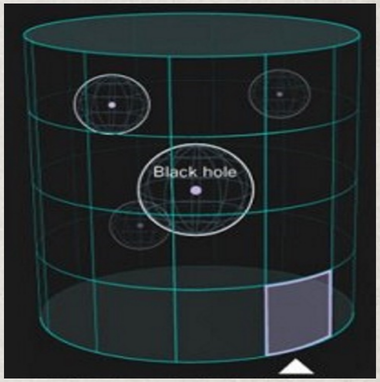
GR + QM → Quantized spacetime

- **Un-controlled quantum fluctuation; singularities …**
- **When Schwarzschild radius = Planck length**
  → Black hole formation: end of short-distance physics!

Quantum Gravity ?




String theory



Holography/AdS-CFT

Nature of BHs: Singularity? Information paradox?
QG: Most challenging endeavor in theoretical physics.

Mysteries remain …

"The best that most of us can hope to achieve in physics is simply to misunderstand at a deeper level."

-- Wolfgang Pauli

Concluding Remarks at the Centennial Celebration

- Quantum mechanics has revolutionized our understanding of Nature.
- It becomes the standard language of modern physics, science and technology.
- Transformative technologies powering the modern world and our lives.
- Key concepts and philosophical questions in QM & QFT remain to be challenging.
- Ongoing research continues to push the boundaries of human knowledge!

Exciting journey in the Second Century of QM!