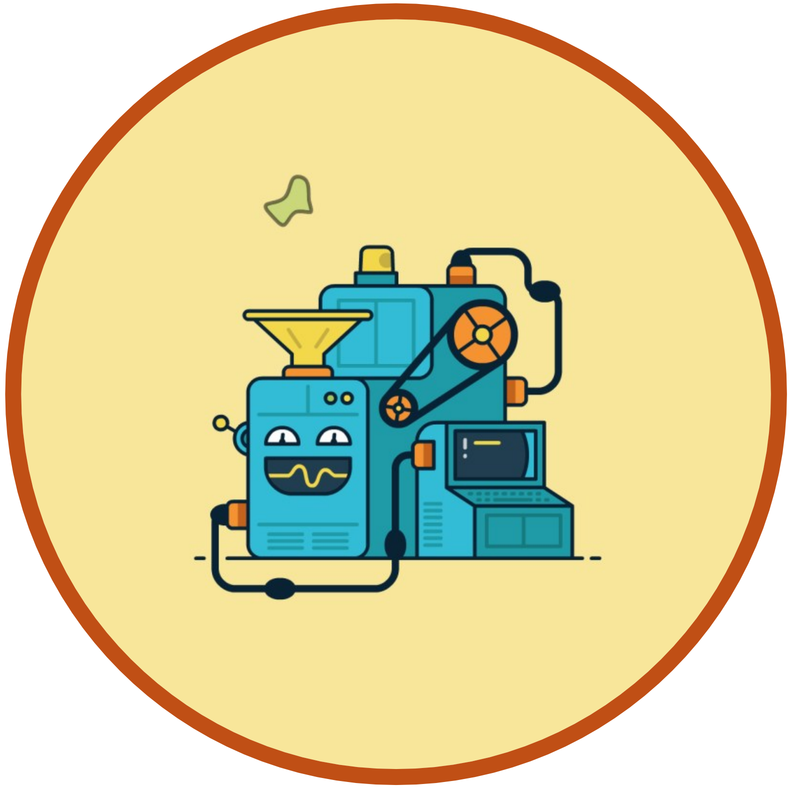
Process Theology as a Lens for Bringing Quantum Physics into Focus

Dr. Michael A. Soderstrand, PhD

Lecture 5: Running the Model: Time Evolution and Becoming → Creative Advance (Ordered process becoming form)

What Is a State Machine?



A state machine is a system that can be in one of several well-defined states.

At any moment:

- The system occupies one state
- Inputs cause transitions to other states

Many everyday systems can be described this way.

Examples include:

- Elevator controllers
- Traffic lights
- Vending machines

We will use a simple vending machine as an example.

Example: Vending Machine States

Our simplified vending machine has four states.

- **State 0 — Ground State (Idle)**
  LED message:
  "Please enter the two-digit number corresponding to the product you would like to purchase."
- **State 1 — Pay State**
  LED message:
  "Please tap your credit card to pay."
- **State 2 — Vending State**
  LED message:
  "Please remove your product from the bottom door."
- **State 3 — Error State**
  LED message:
  "Sorry, there has been an error. Please hit any button to reset."

At any moment the machine is in exactly one of these states.

Example: Vending Machine States

Transitions Between States:

Examples:

- Idle → Pay (customer enters valid product number)
- Pay → Vending (payment is approved)
- Vending → Idle (customer removes product)
- Any state → Error (invalid input, payment failure, mechanical problem)

These transition rules determine how the machine evolves over time.

In computer science this transition rule is the logic of the machine.

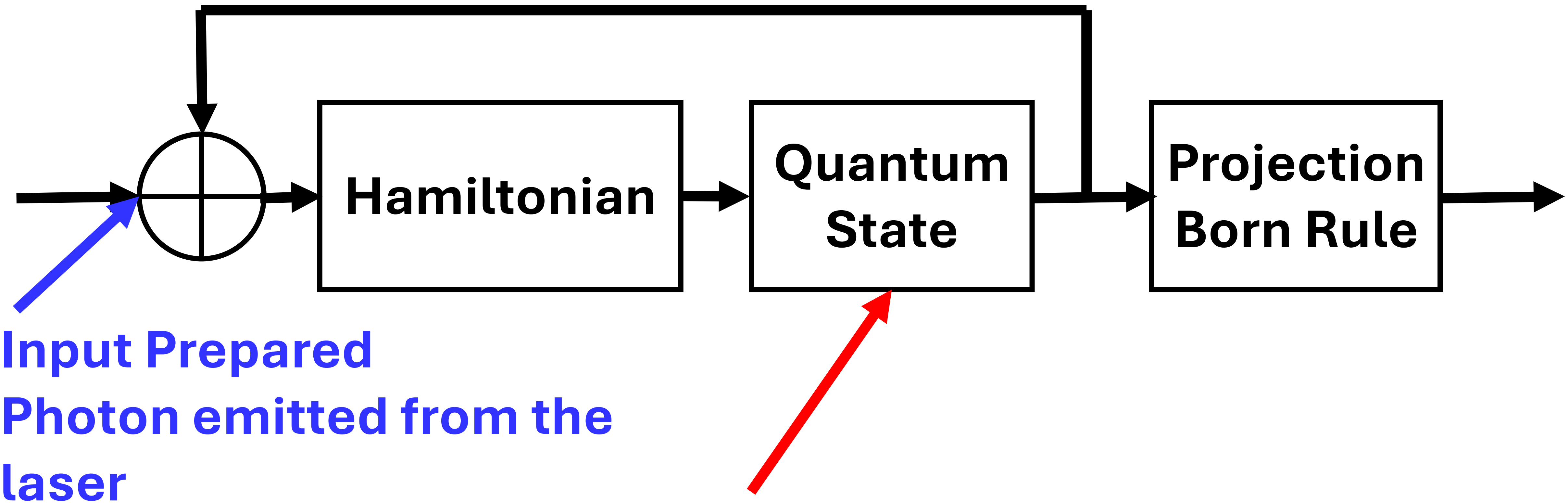
Example: Vending Machine States

Connecting the Example to Physics:
This simple machine illustrates three important ideas.

1. **State Space**
   The list of possible states the system can occupy. In quantum physics the state space is called **Hilbert Space**.
2. **Evolution Rule**
   Rules that determine how the system moves from one state to another. In quantum physics these evolution rules are generated by the **Hamiltonian**.
3. **Observable Output**
   The LED display tells the user what state the machine is in. In physics we also need a rule that connects the quantum state to what we observe in experiments (**The Born Rule**).

With this idea in mind, we can now build a **state machine description of quantum physics**.

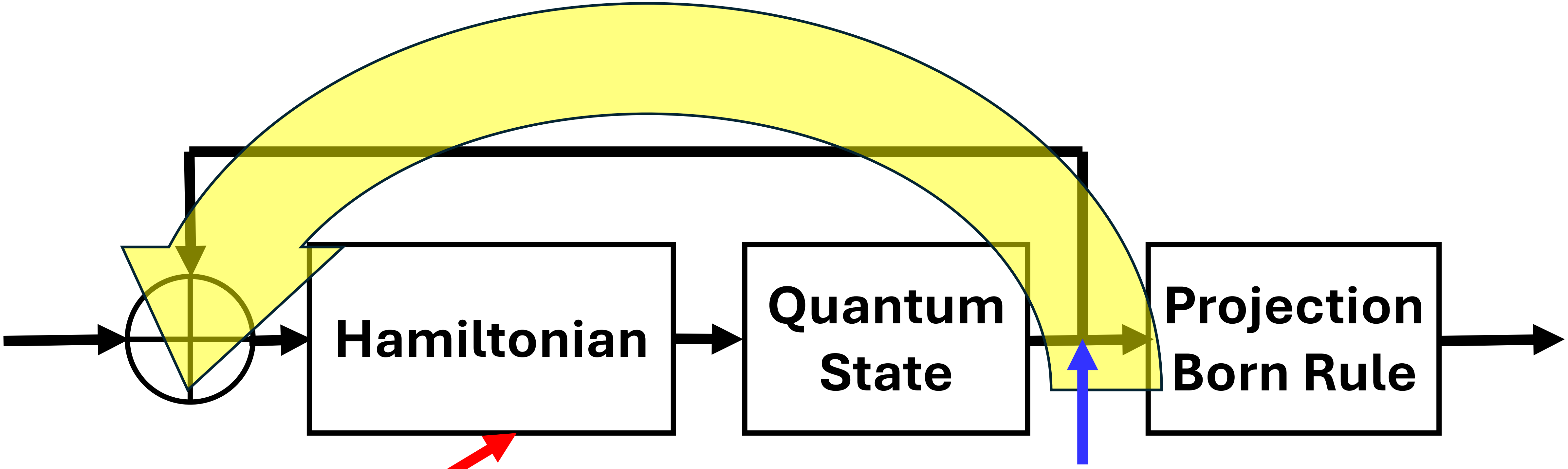
The Quantum Field Theory (QFT) Model



Input Prepared Photon emitted from the laser

Starts in the Vacuum State
No particles present

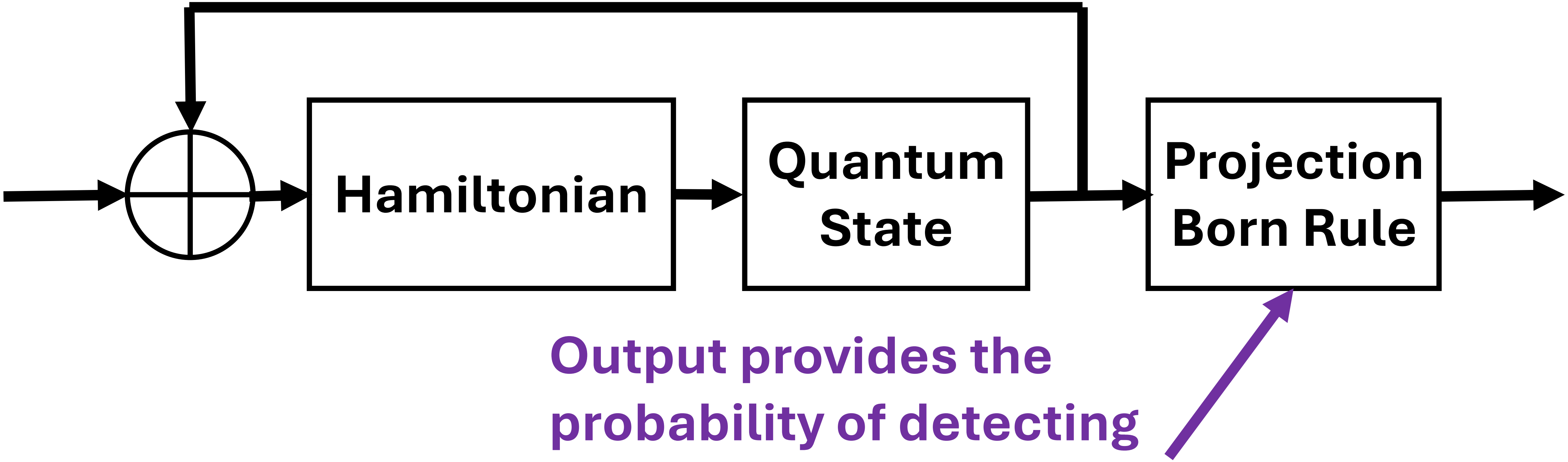
The Quantum Field Theory (QFT) Model



The Hamiltonian determines the evolution from the vacuum state to a state containing one photon.

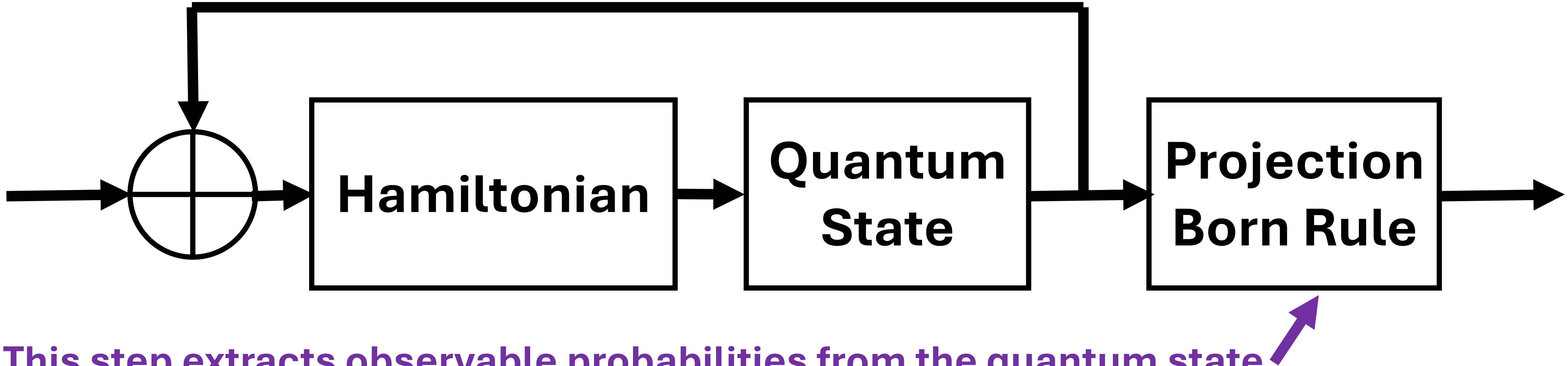
The feedback loop repeatedly updates the quantum description of the photon as it propagates through space and time.

The Quantum Field Theory (QFT) Model



Output provides the probability of detecting the particle at any point in spacetime.

The Quantum Field Theory (QFT) Model



This step extracts observable probabilities from the quantum state.
In simple cases, this is done by changing basis and applying the Born rule.
More generally, it involves applying a measurement operator—constructed from the same operators that define the model—and then using the Born rule to obtain probabilities.

The Result of Running the Model

The experiment:

- Sending one photon at a time from a laser to a detector

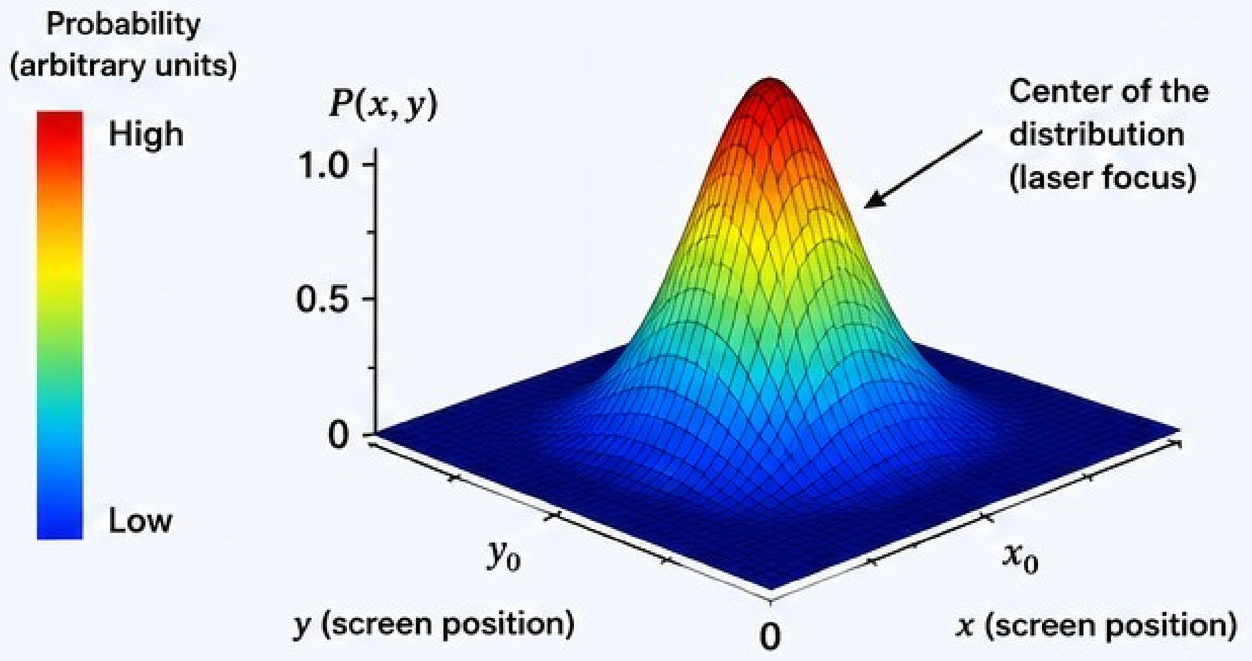
What is the result of running the model?

- Each individual photon is detected at one location sampled from this probability distribution.

1. Probability Distribution (Theoretical Prediction)

The model's output is the probability $P(x, y)$ of detecting the photon at each point (x, y) on the screen.
For this simple setup, the probability distribution is a 2-D Gaussian centered on the laser's focal point.

$$P(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} \exp\left[-\left(\frac{x-x_0}{2\sigma_x^2} + \frac{y-y_0}{2\sigma_y^2}\right)\right]$$



This is the probability of detecting the photon at each point on the screen.

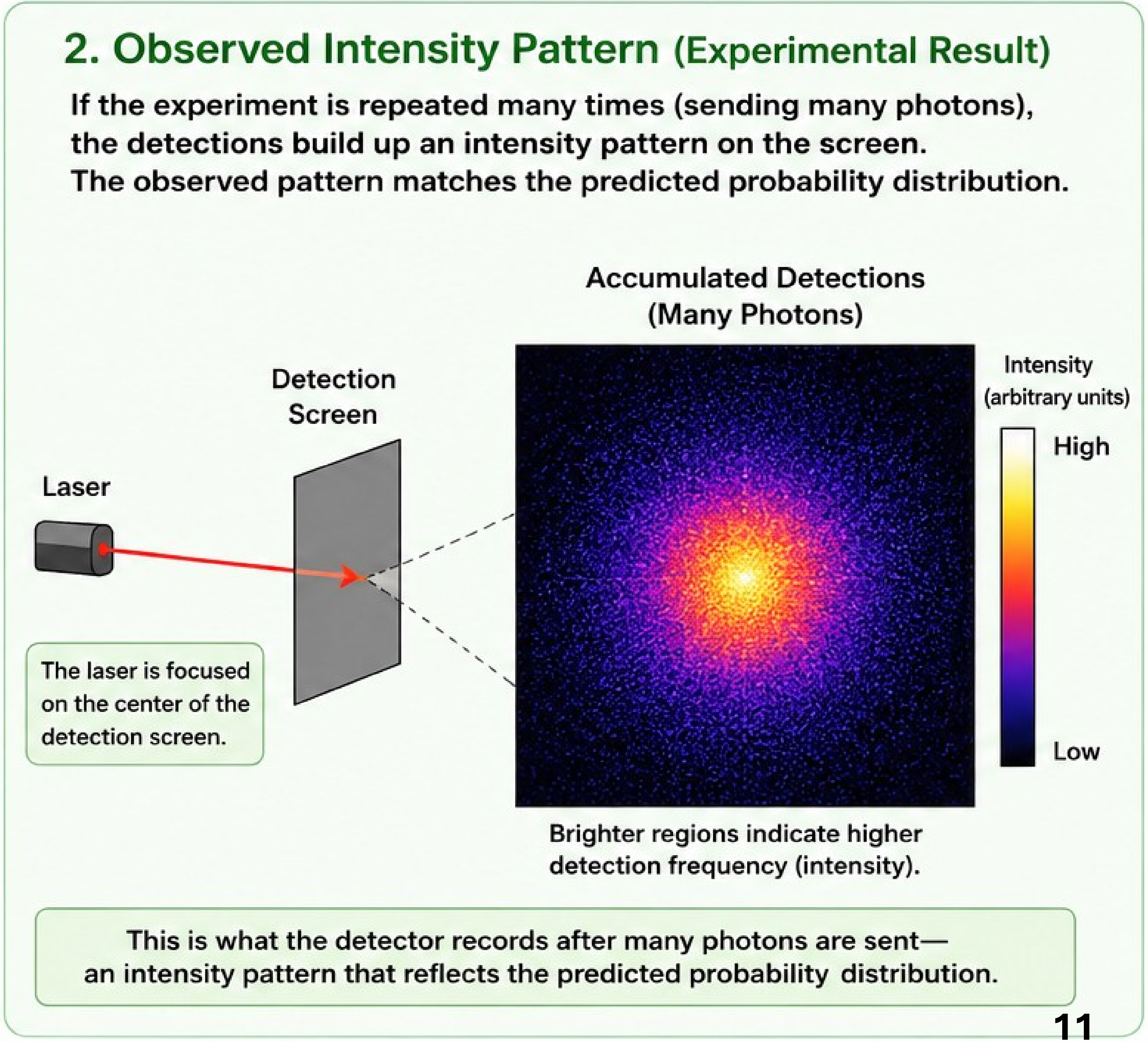
The Result of Running the Model

The experiment:

- Sending one photon at a time from a laser to a detector

What is the result of running the model?

- After many photons, the accumulated detections reproduce the predicted probability distribution.



A Process Theology Perspective

The Superjective Nature of God

The Quantum State Machine has evolved the quantum state from the emission of a single photon to a prediction of where that photon may be detected.

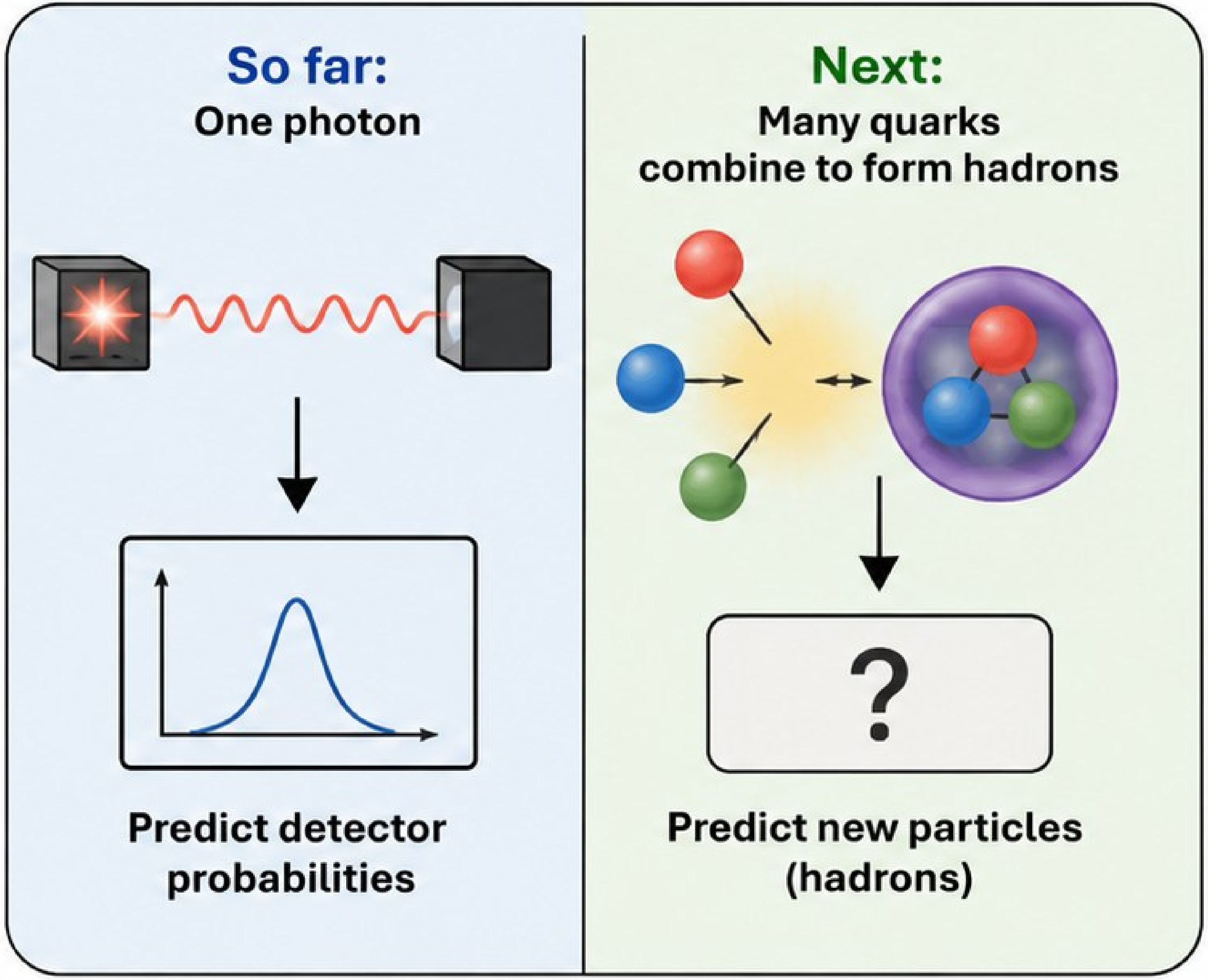
- From a Process Theology perspective,
    - The Hamiltonian may be understood as describing the Superjective Nature of God—the continual lure guiding the process of becoming.
    - The quantum state represents the unfolding process of becoming.
    - The Born Rule reveals the probability distribution toward which the process of becoming has been guided.
    - Individual photon detections are Actual Occasions.
    - As more and more Actual Occasions occur, they gradually reveal the probability distribution—the emergent pattern toward which the lure has been guiding the process.

The Process Theology Lens

Key Idea

- The lure does not determine a single event.
- It guides the process toward an emergent pattern that becomes visible only through many Actual Occasions.

From Predicting Experiments to Predicting New Particles



Up to now...

- We have used the quantum state machine to predict the outcome of one simple experiment:
    - Prepare one photon
    - Run the Hamiltonian
    - Apply the Born Rule
    - Predict where the photon may be detected

Now we ask a much bigger question...

- Can the same quantum state machine predict entirely new particles?
    - Not detector patterns...
    - ...but predict the stable building blocks of matter itself.

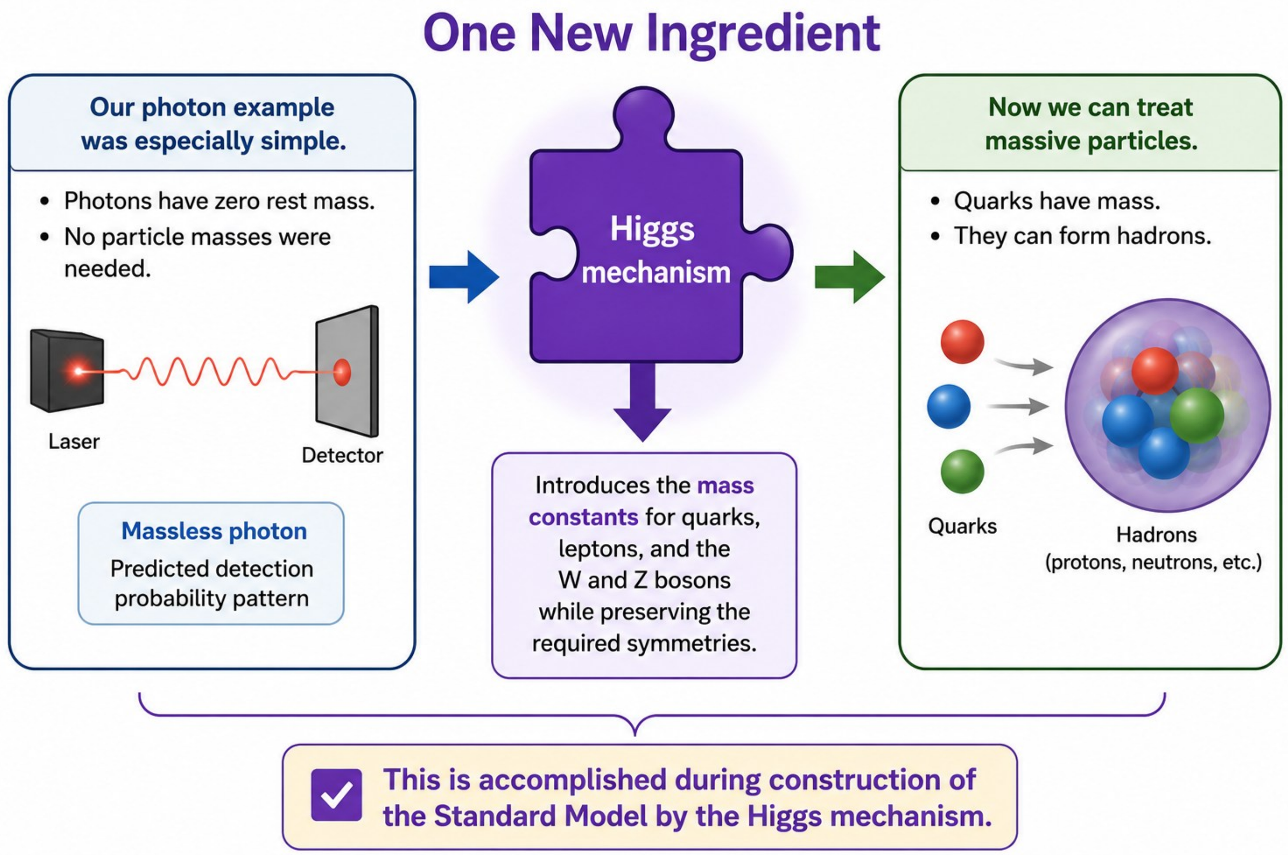
One More Ingredient Before We Continue

Our photon example was especially simple.

- Photons have zero rest mass.
- No particle masses were needed.
- Quarks, however, do have mass.

Before we can run the quantum state machine for quarks and hadrons, the Hamiltonian must already contain the masses of the elementary particles.

- This is accomplished during construction of the Standard Model by the Higgs mechanism.
- After that construction is complete,
- the Hamiltonian is finished and ready to run.



The Higgs Mechanism: Separating Fact from Fiction

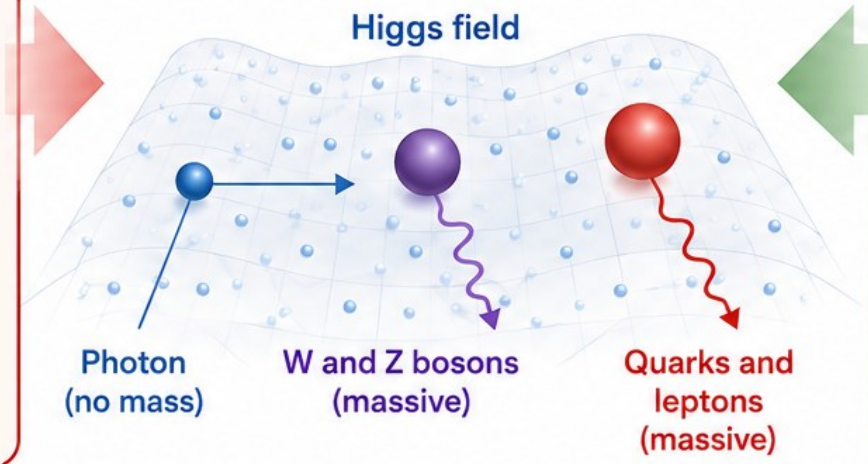
Before we continue, let's clear away a few common misconceptions.

✖ FICTION

❌ ***"The Higgs boson gives particles their mass."***

The Higgs Mechanism

Introduces mass constants for particles while preserving the symmetries of the theory.



✔ FACT

✓ The Higgs mechanism is the part of the Standard Model that introduces the particle mass constants into the Hamiltonian while preserving the theory's required symmetries.

1. **During construction** — The Higgs mechanism *adds the mass terms to the Hamiltonian.* →
2. **Construction complete** — The Hamiltonian now contains all the mass constants. →
3. **Now we run the model** — The Higgs mechanism has already done its job. It *does not* appear in the calculations.

→ **The Higgs mechanism is part of building the machine — not part of running it.**

The Higgs Mechanism: Separating Fact from Fiction

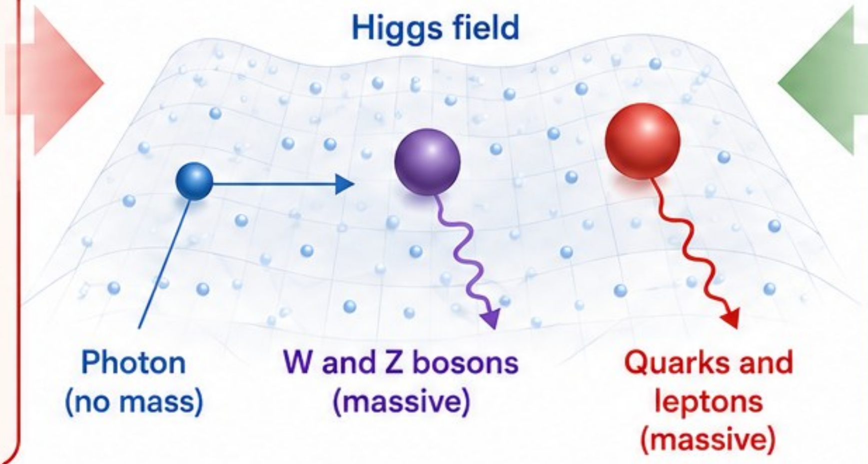
Before we continue, let's clear away a few common misconceptions.

✖ FICTION

❌ **"Particles get mass by plowing through an invisible Higgs molasses."**

The Higgs Mechanism

Introduces mass constants for particles while preserving the symmetries of the theory.



✔ FACT

✓ **That analogy is memorable but misleading. Mass is not the result of friction or drag.**

1. **During construction** — *The Higgs mechanism adds the mass terms to the Hamiltonian.*
2. **Construction complete** — The Hamiltonian now contains all the mass constants.
3. **Now we run the model** — The Higgs mechanism has already done its job. It *does not* appear in the calculations.

→ **The Higgs mechanism is part of building the machine — not part of running it.**

The Higgs Mechanism: Separating Fact from Fiction

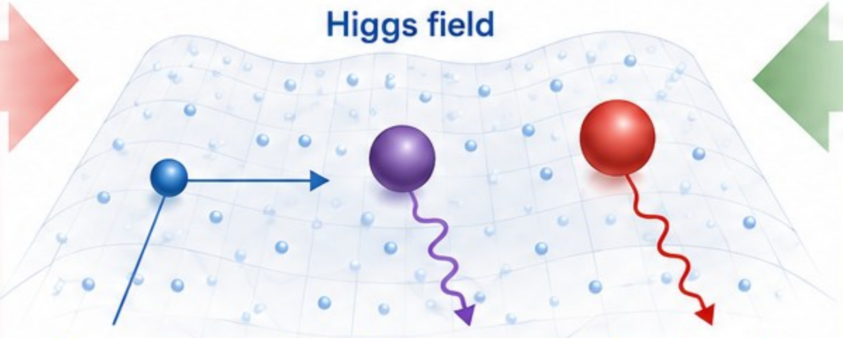
Before we continue, let's clear away a few common misconceptions.

❌ FICTION

❌ **"The Higgs boson is the God Particle."**

The Higgs Mechanism

Introduces mass constants for particles while preserving the symmetries of the theory.



✅ FACT

✓ **This nickname came from a popular science book, not from physics. It has no scientific meaning and no connection to theology (It was actually the God Damn Particle!).**

1. **During construction** — *The Higgs mechanism adds the mass terms to the Hamiltonian.*
2. **Construction complete** — The Hamiltonian now contains all the mass constants.
3. **Now we run the model** — The Higgs mechanism has already done its job. It *does not appear* in the calculations.

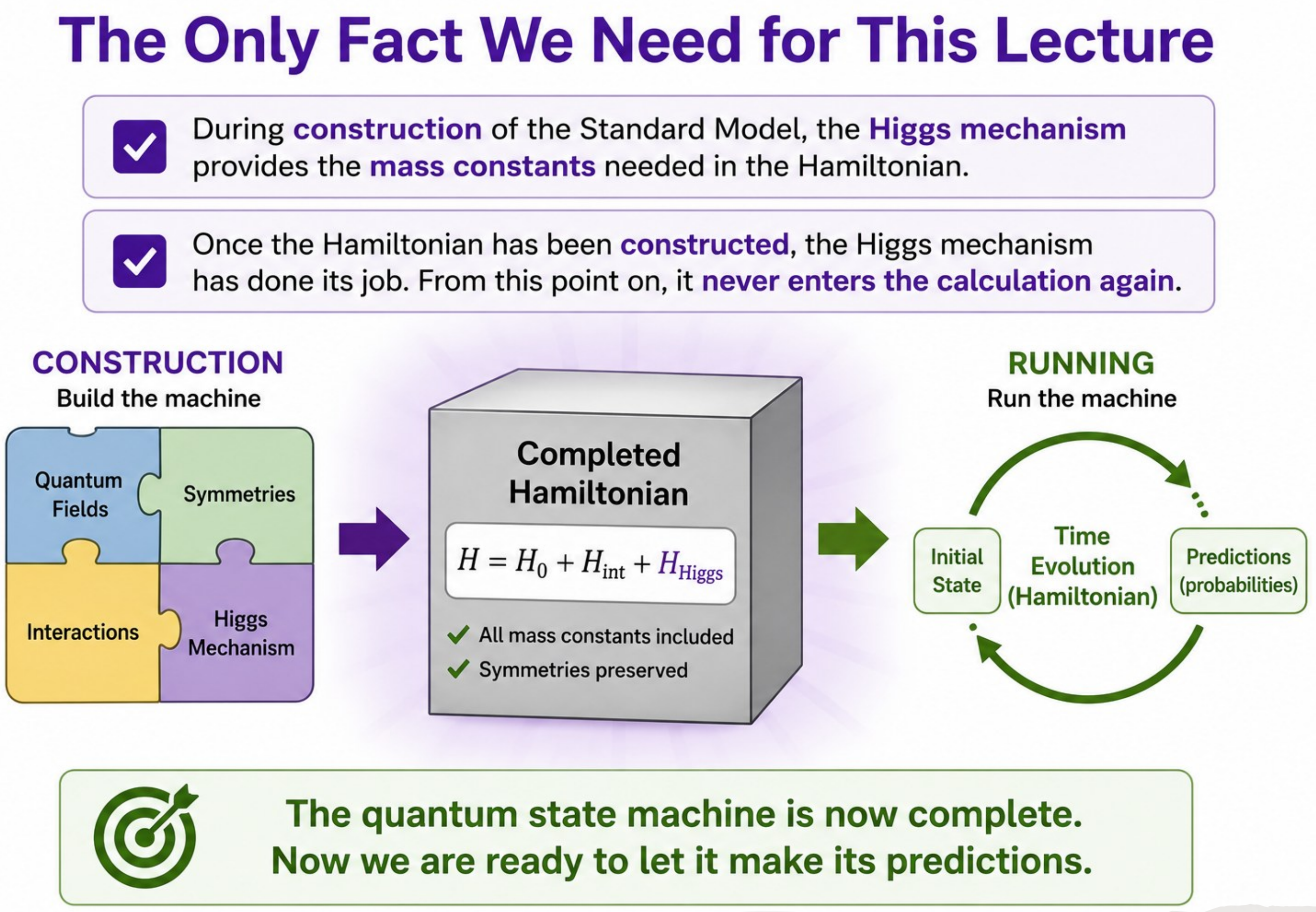
→ The Higgs mechanism is part of building the machine — not part of running it.

The Higgs Mechanism: Separating Fact from Fiction

The Only Fact We Need for This Lecture

- ✓ During construction of the Standard Model, the Higgs mechanism provides the mass constants needed in the Hamiltonian.
- ✓ Once the Hamiltonian has been constructed, the Higgs mechanism has already done its job.
- ✓ From this point on, it never enters the calculation again.

Now we are ready to let the completed Quantum State Machine make its predictions.



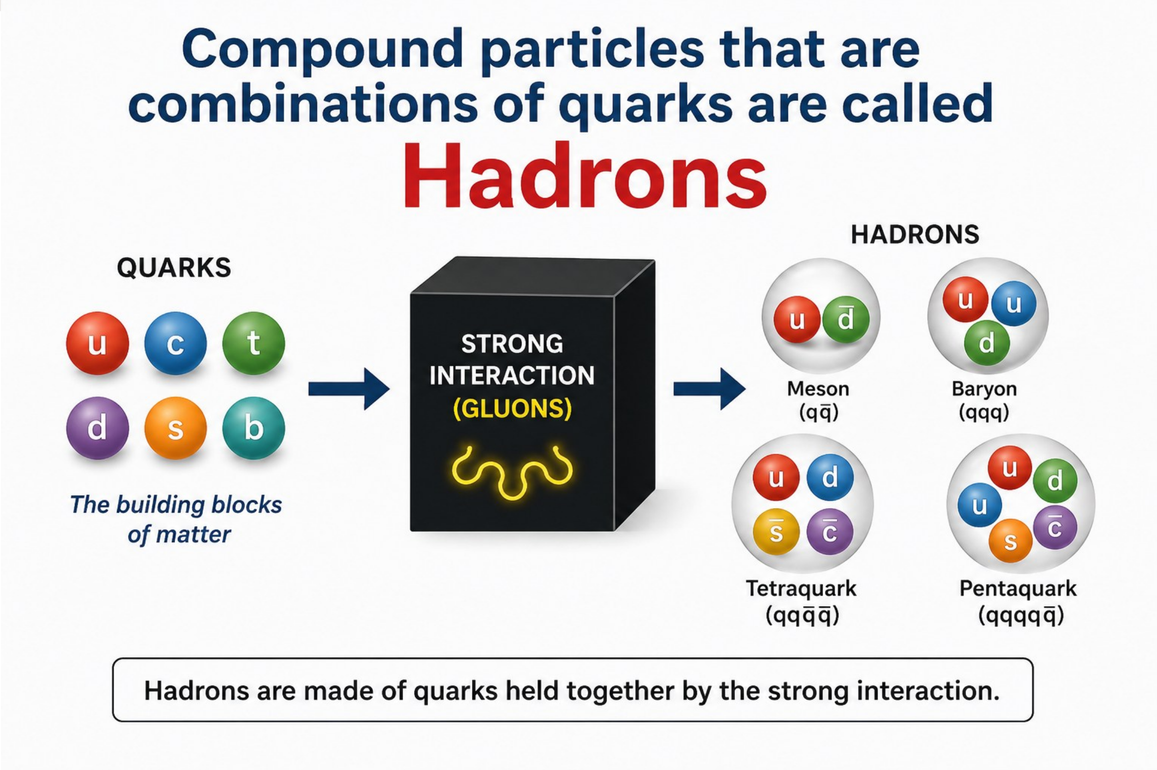
Running the Model to Predict Hadrons

Question

- **Can the same Quantum State Machine predict particles made from multiple quarks?**

Answer

- **Yes!**
- **With the completed Hamiltonian—including the particle masses introduced during model construction—we now prepare different combinations of quarks and allow the Hamiltonian to evolve the quantum state.**



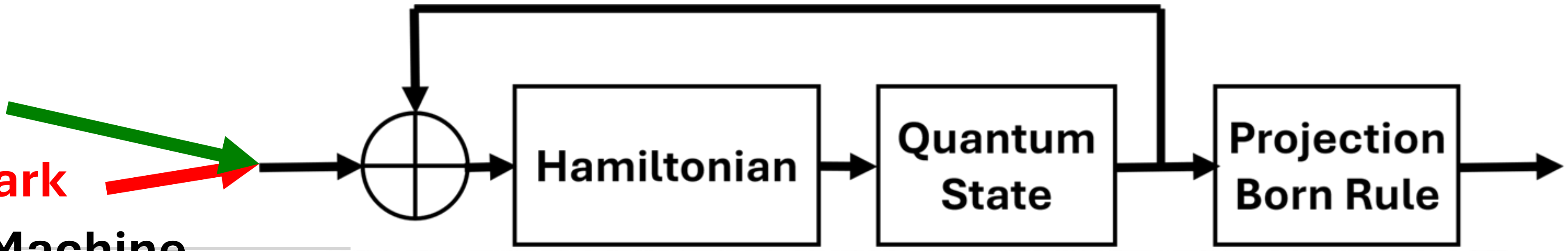
The Strong Interaction

- **Gluons mediate the strong interaction between quarks.**
- **The Hamiltonian evolves the quantum state until stable bound states emerge.**
- **The same Quantum State Machine that predicted the detection of a single photon now predicts the structure of matter.**

Mesons — Two-Quark Bound States

Prepared Input

- One quark
- One antiquark



Quantum State Machine Prediction

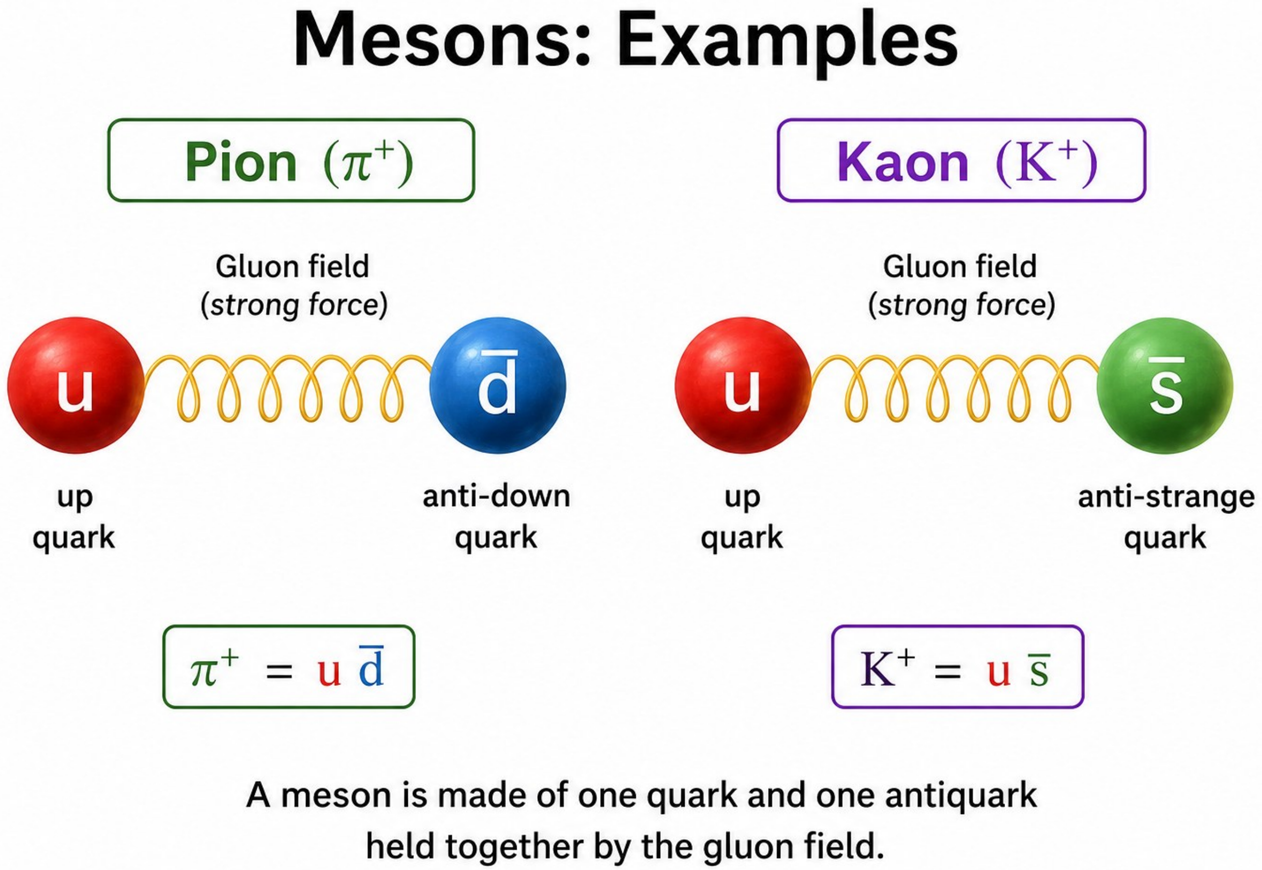
- Stable two-quark bound states called mesons

Examples

- Pions
- Kaons

Key Idea

- The same Hamiltonian that evolved a single photon now predicts stable quark–antiquark bound states.



How Many Mesons Does the Model Predict?

The model predicts hundreds of mesons

- There are six quarks and six anti-quarks so you might think there are only 36 mesons
- However, the top quark and top anti quark decay too rapidly to combine with other quarks so that would appear to generate 25 mesons
- But when we combine elementary particles some may be spin up and some spin down, different parity, different excited states — this results in hundreds of mesons.
- All are predicted by the model

Quark–Antiquark Combinations (Mesons)

Each cell shows a possible meson flavor combination $q\bar{q}'$.
Each combination can exist in many different quantum states.

ANTIQUARK ($\bar{q}'$)

QUARK (q)	$\bar{u}$ (anti-up)	$\bar{d}$ (anti-down)	$\bar{s}$ (anti-strange)	$\bar{c}$ (anti-charm)	$\bar{b}$ (anti-bottom)
u (up)	$u\bar{u}$ (e.g., π^0, η)	$u\bar{d}$ (e.g., π^+)	$u\bar{s}$ (e.g., K^+)	$u\bar{c}$ (e.g., D^0)	$u\bar{b}$ (e.g., B^+)
d (down)	$d\bar{u}$ (e.g., π^-)	$d\bar{d}$ (e.g., π^0, η)	$d\bar{s}$ (e.g., K^0)	$d\bar{c}$ (e.g., D^-)	$d\bar{b}$ (e.g., B^0)
s (strange)	$s\bar{u}$ (e.g., K^-)	$s\bar{d}$ (e.g., $\bar{K}^0$)	$s\bar{s}$ (e.g., ϕ)	$s\bar{c}$ (e.g., D_s^-)	$s\bar{b}$ (e.g., B_s^0)
c (charm)	$c\bar{u}$ (e.g., D^+)	$c\bar{d}$ (e.g., D^0)	$c\bar{s}$ (e.g., D_s^+)	$c\bar{c}$ (e.g., J/ψ, η_c, $\psi(2S)$, χ_c)	$c\bar{b}$ (e.g., B_c^+)
b (bottom)	$b\bar{u}$ (e.g., B^-)	$b\bar{d}$ (e.g., $\bar{B}^0$)	$b\bar{s}$ (e.g., B_s^0)	$b\bar{c}$ (e.g., B_c^-)	$b\bar{b}$ (e.g., $\Upsilon(1S)$, $\Upsilon(2S)$, χ_b)

Note: The top quark (t) [illegible] decays via the weak interaction before it can form hadrons, so no mesons (or baryons) containing t or $\bar{t}$ have been observed.

Total: **5 quark flavors × 5 antiquark flavors = 25** possible flavor combinations.
Each can exist in many different quantum states (different spin, parity, excitations, etc.).

A Process Theology Perspective

The Same Lure...Greater Complexity

- The same Quantum State Machine that predicts the behavior of a single photon also predicts the existence of an entire family of mesons.

From a Process Theology perspective,

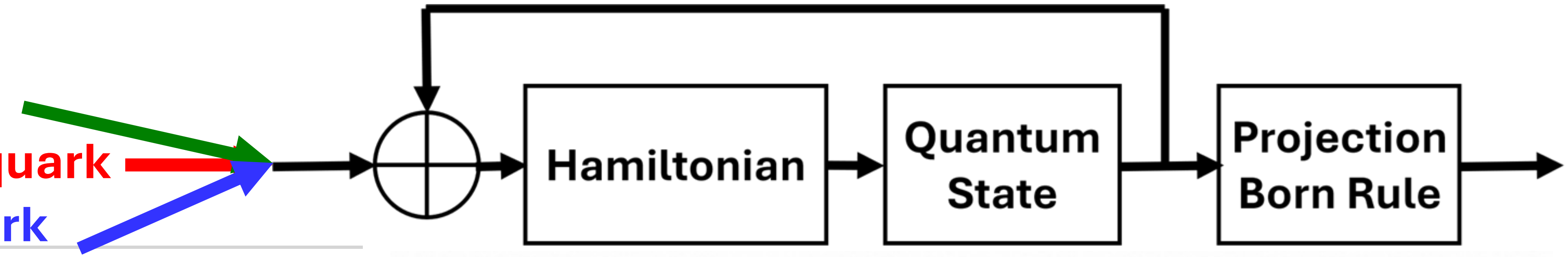
- The Superjective Nature of God is not confined to simple systems.
- The same lure guides the evolution of every quantum state, whether describing a photon or a quark–antiquark system.
- Experimental observations of mesons are Actual Occasions.
- Together they reveal the deeper mathematical pattern predicted by the Quantum State Machine.

The Process Theology Lens

Key Idea

One lure...many different expressions of becoming.

Baryons — Three-Quark Bound States



Prepared Input

- One quark
- A second quark
- A third quark

Quantum State Machine Prediction

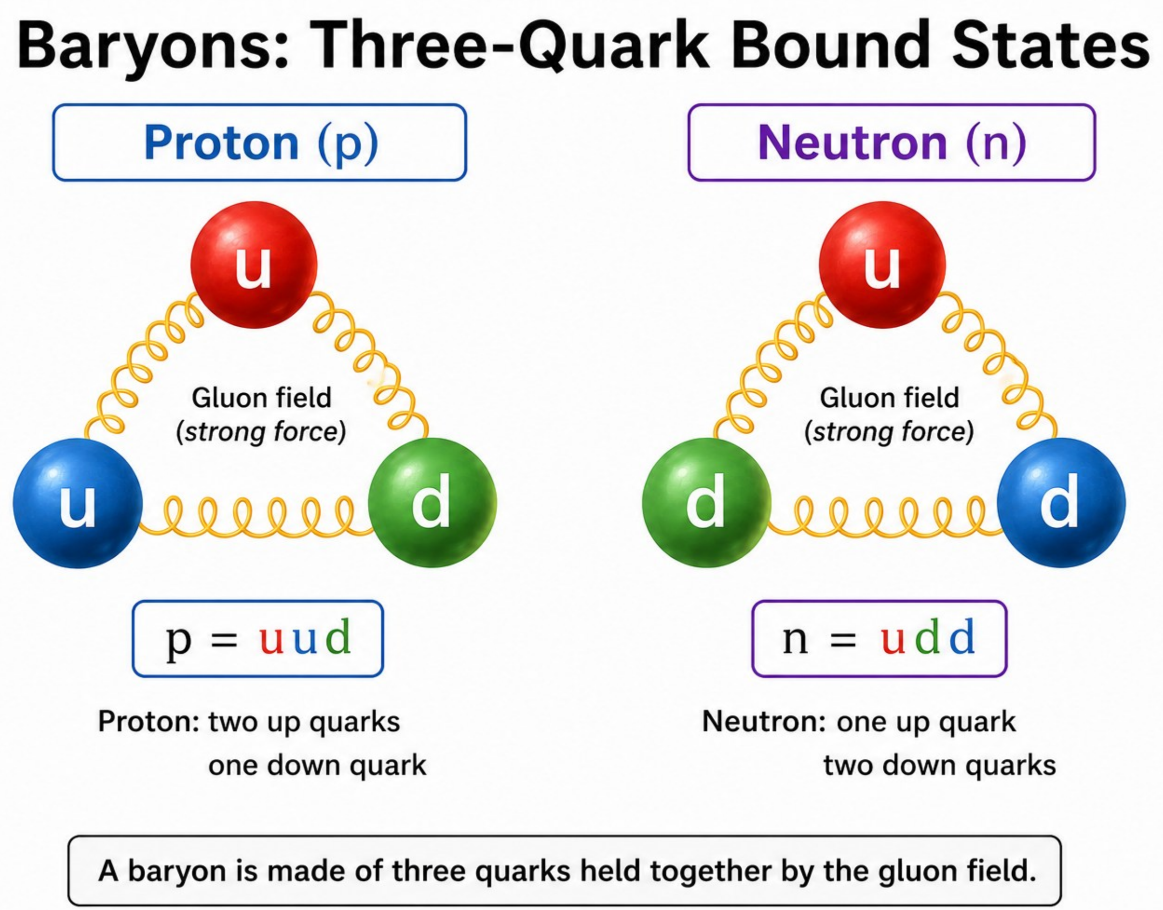
- Stable three-quark bound states called baryons

Examples

- Proton
- Neutron

Key Idea

- The same Hamiltonian that evolved a single photon now predicts stable three-quark bound states.



How Many Baryons Does the Model Predict?

The model predicts hundreds of baryons

- There are 5 quark flavors (u, d, s, c, b) excluding the top quark
- Since the order doesn't matter—a proton is the same whether you write uud, udu, or duu—there are exactly 35 distinct flavor combinations.
- Each flavor combination can exist in many quantum states (Spin, Orbital angular momentum, Parity, Excited energy levels).
- Result: Hundreds of baryons predicted by the model and observed experimentally.
- All are predicted by the model

THREE-QUARK COMBINATIONS (BARYONS)

All 35 distinct combinations of three quarks using the five flavors (u, d, s, c, b)

FIRST QUARK	Third Quark				
	u (up)	d (down)	s (strange)	c (charm)	b (bottom)
u (up)	1 uuu (e.g., Δ^{++})	2 uud (e.g., proton)	3 uus (e.g., Σ^+)	4 uuc (e.g., Σ_c^+)	5 uub (e.g., Σ_b^+)
d (down)		6 ddd (e.g., Δ^-)	7 dds (e.g., Σ^-)	8 ddc (e.g., Ξ_c^+)	9 ddb (e.g., Ξ_b^0)
s (strange)			10 sss (e.g., Ω^-)	11 ssc (e.g., Ξ_c^+)	12 ssb (e.g., Ξ_b^0)
c (charm)				13 ccc (e.g., Ω^0_{ccc})	14 ccb (e.g., Ξ^+_{cb})
b (bottom)					15 bbb (e.g., Ω^0_{bbb})

COUNTING THE 35 COMBINATIONS

1. All three the same (5 combinations) — **5**
   uuu, ddd, sss, ccc, bbb
2. Two the same, one different (20 combinations) — **20**
   Examples: uud, uus, uuc, uub, udd, dds, ...
3. All three different (10 combinations) — **10**
   Examples: uds, udc, udb, usc, usb, ucb, ...

Total = 5 + 20 + 10 = **35**

THE REMAINING 20 COMBINATIONS (NOT REPEATED IN THE TABLE ABOVE)

Two the same, one different (other 10)

16	ddu	(e.g., neutron)	21	scu	(e.g., Ξ_c^0)
17	dsu	(e.g., Σ^0 or Λ)	22	sbu	(e.g., Ξ_b^0)
18	dcu	(e.g., Λ_c^+)	23	ccu	(e.g., Ξ_{cc}^+)
19	dbu	(e.g., Λ_b^0)	24	cbu	(e.g., Ξ_{cb}^0)
20	ssu	(e.g., Σ^0 or Λ)	25	bbu	(e.g., Σ_b^-)

All three different (10)

26	uds	(e.g., Λ^0 or Σ^0)	31	ucb	(e.g., Ω_{cb}^0)
27	udc	(e.g., Λ_c^+)	32	dsc	(e.g., Ξ_c^+)
28	udb	(e.g., Λ_b^0)	33	dsb	(e.g., Ξ_b^0)
29	usc	(e.g., Ξ_c^+)	34	dcb	(e.g., Ω_{cb}^0)
30	usb	(e.g., Ξ_b^0)	35	scb	(e.g., Ω_{cb}^0)

A Process Theology Perspective

Building the Stable Matter of the Universe

- The Quantum State Machine now predicts the stable baryons that make ordinary matter possible.

From a Process Theology perspective,

- The Superjective Nature of God continues to guide the process of becoming.
- Rather than separate acts of creation, the proton and neutron may be understood as new expressions of the same quantum dynamics.
- As experiments observe many Actual Occasions, the underlying probability patterns predicted by the Born Rule become increasingly apparent.

The Process Theology Lens

Key Idea

The same lure that guides a single photon also guides the emergence of the stable building blocks of matter.

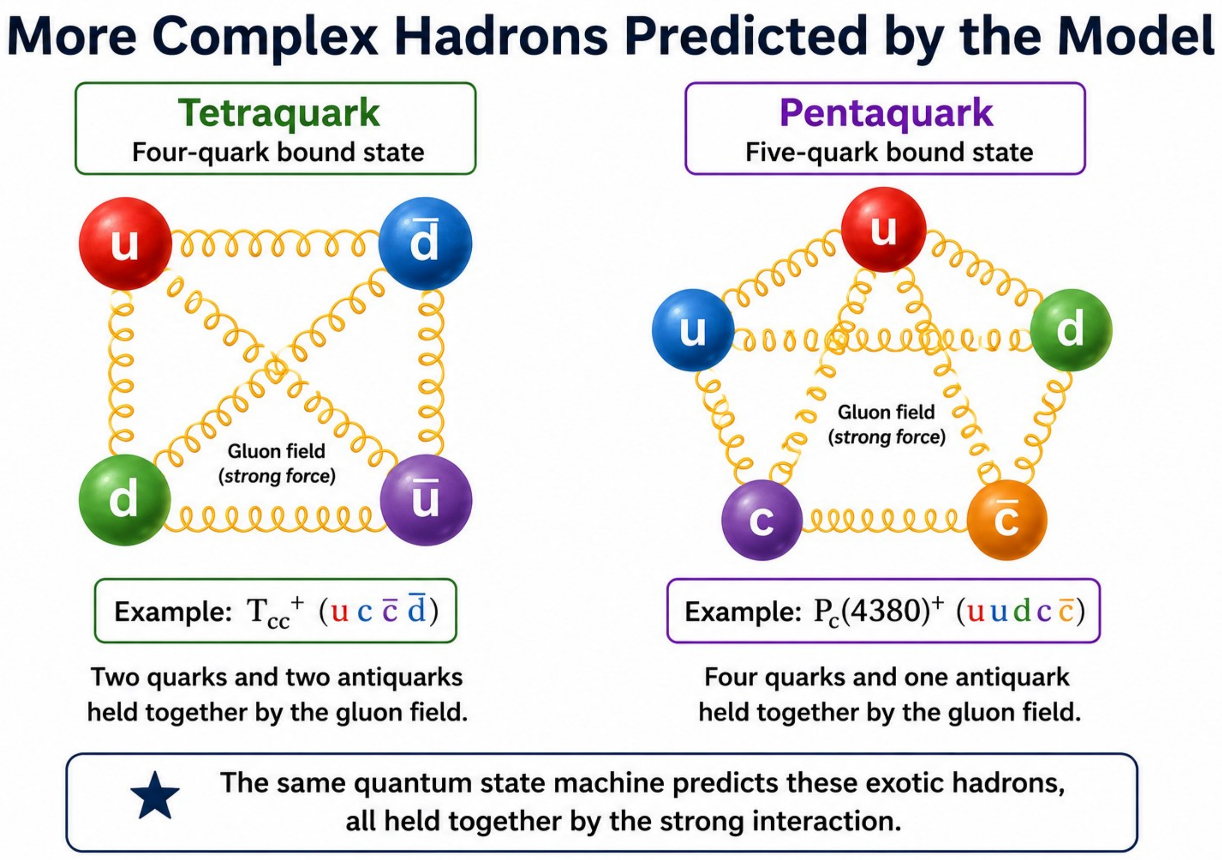
More Complex Hadrons

The same quantum state machine predict even richer combinations of quarks.

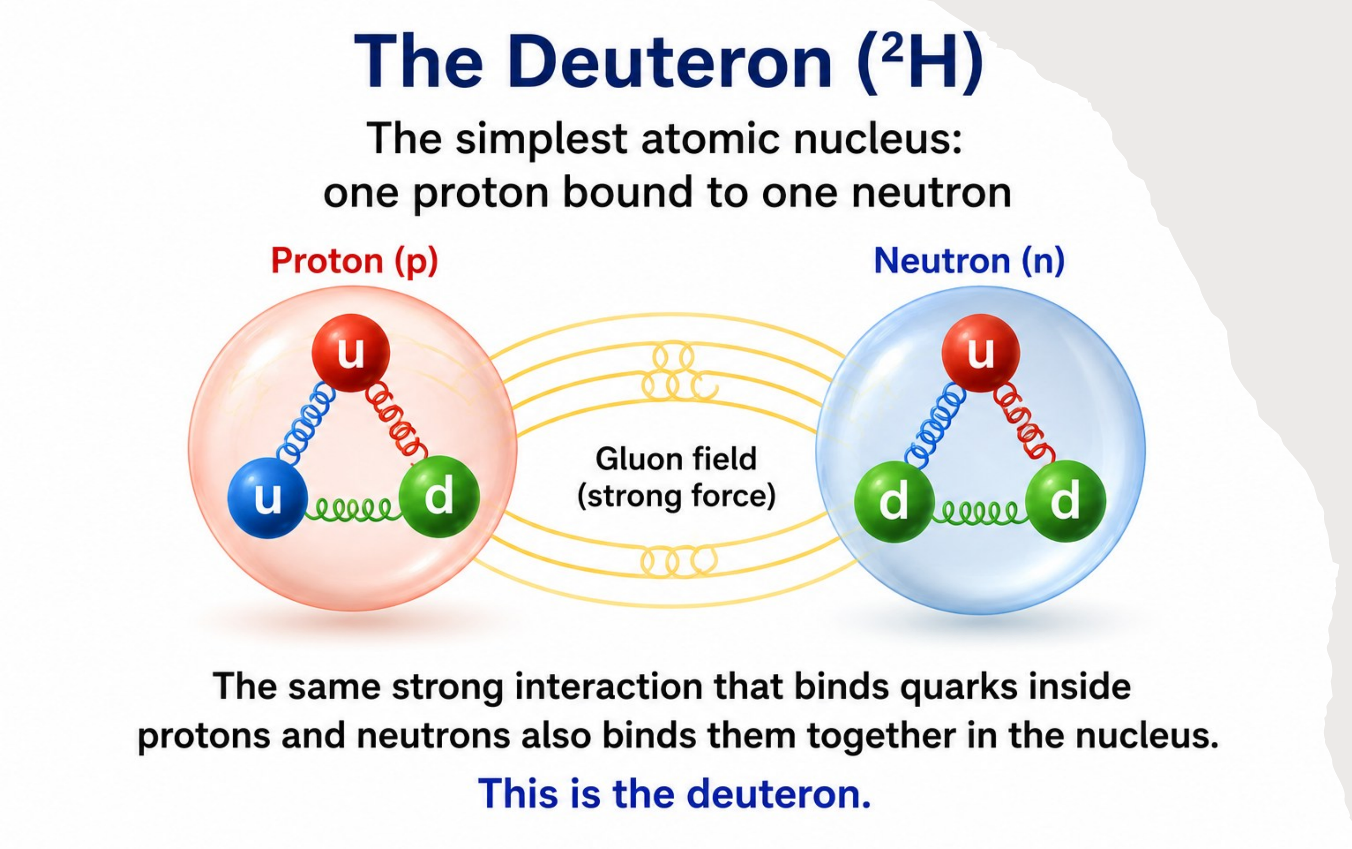
- **Tetraquarks**
  - **Four-quark bound states**
- **Pentaquarks**
  - **Five-quark bound states**
- **These exotic hadrons were predicted by the quantum state machine and later confirmed experimentally.**

Key Idea

- **The same Hamiltonian successfully predicts increasingly complex bound states without changing the underlying theory.**



From Hadrons to Atomic Nuclei



The quantum state machine predicts not only individual hadrons but also the interactions that build atomic nuclei.

The Deuteron

- **One proton bound to one neutron**
- **The simplest atomic nucleus after hydrogen**
- **The same strong interaction that binds quarks into protons and neutrons also gives rise to the force that binds nuclei together.**

Modern Confirmation

- **Physicists have also discovered rare six-quark bound states such as the d(2380)*.**
- **These states were predicted by the quantum state machine model before they were experimentally confirmed.**

Key Idea

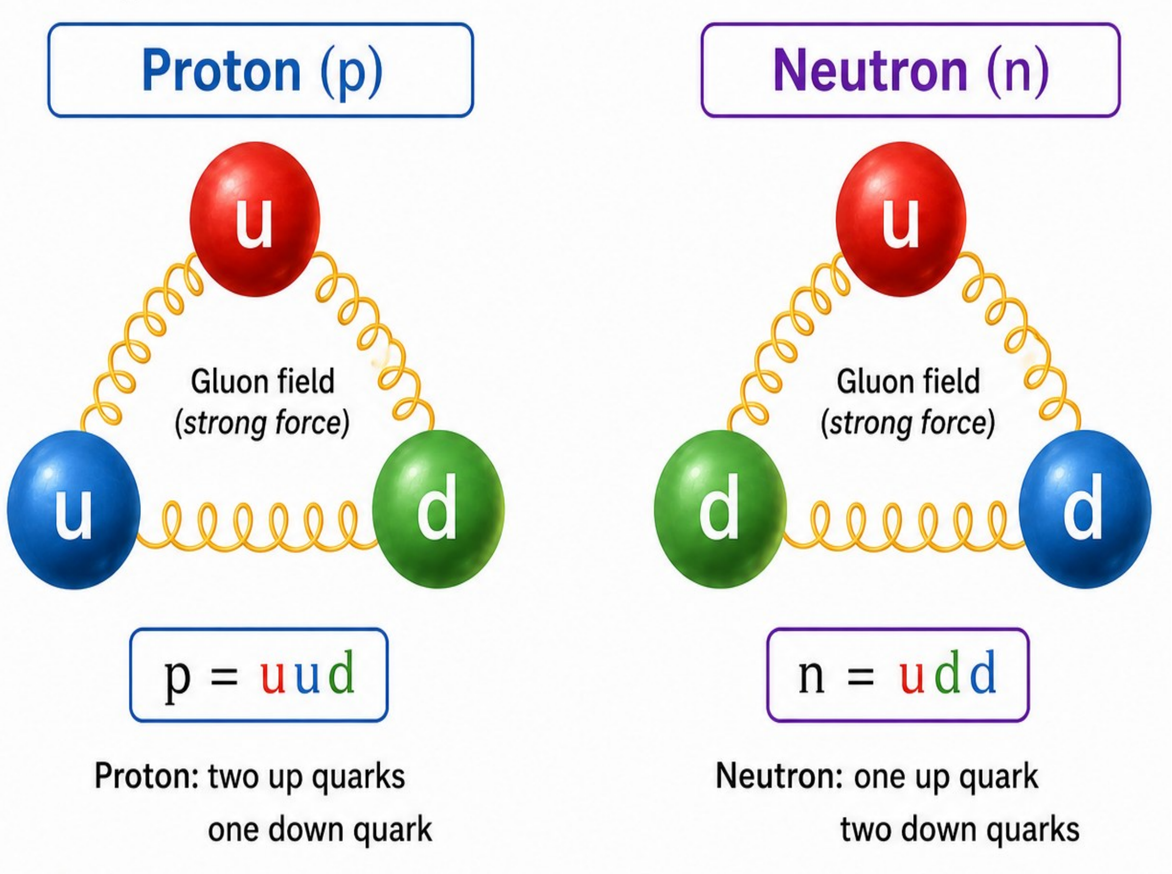
- **The same quantum state machine predicts the structure of matter—from single particles to atomic nuclei—without changing the underlying theory.**

Looking More Closely at the Proton and Neutron

The Quantum State Machine predicts many different baryons.

Let's look more closely at the two that make up nearly all of the ordinary matter around us.

- **Proton**
  - **Up + Up + Down (uud)**
- **Neutron**
  - **Up + Down + Down (udd)**

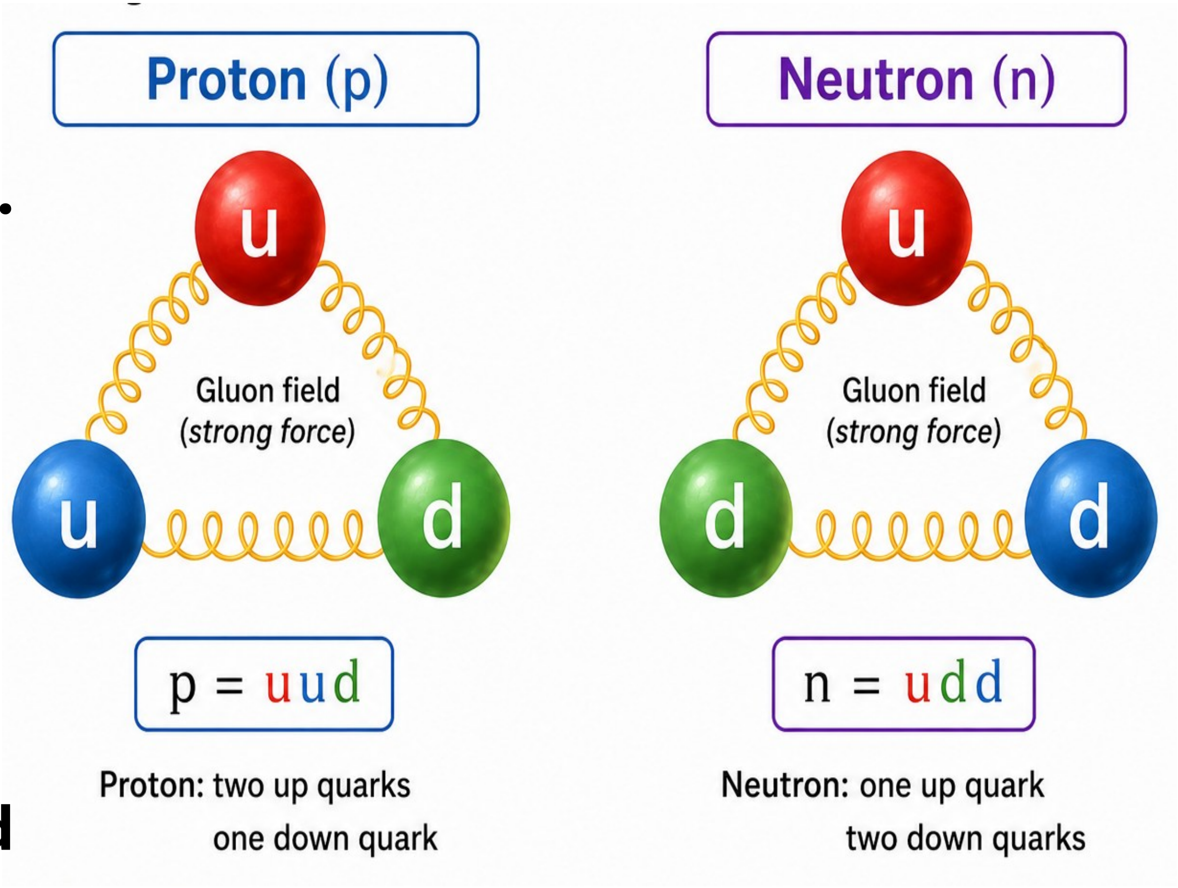


Looking More Closely at the Proton and Neutron

The Quantum State Machine predicts much more than their quark composition.

- **It also predicts:**
  - **their rest masses**
  - **their electric charges**
  - **their magnetic moments**
  - **their spins**
  - **their stability**

Every one of these predictions can be and has been tested experimentally.

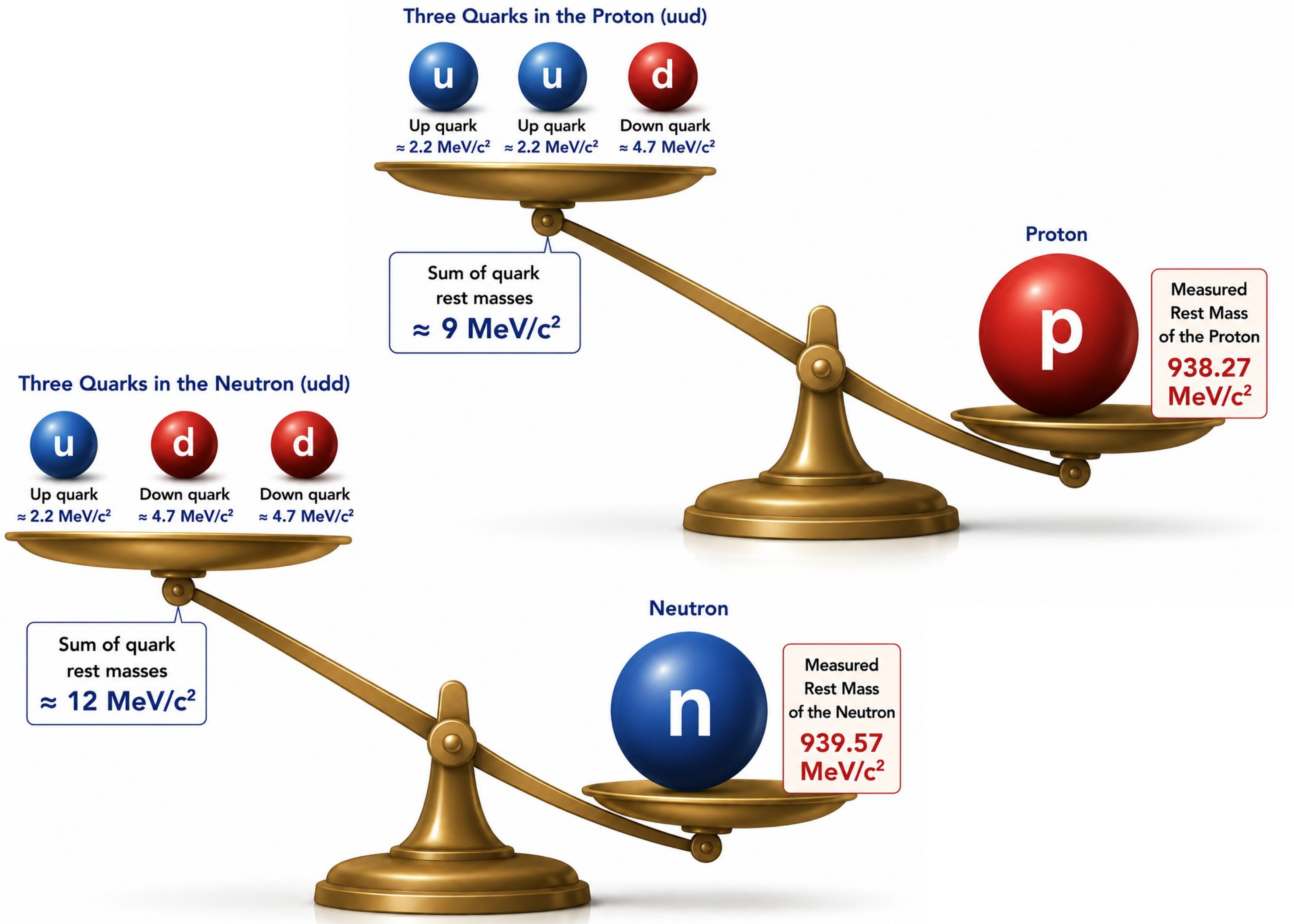


Our First Surprise: Where Does the Mass Come From?

Since the proton and neutron are made from three quarks, we might naturally expect:

- Rest Mass of Proton = Sum of the Rest Masses of its Quarks
- Rest Mass of Neutron = Sum of the Rest Masses of its Quarks

Let's see what the Quantum State Machine predicts...



The quarks account for only about 1% of the proton's and neutron's rest mass!

Where does the other 99% come from?

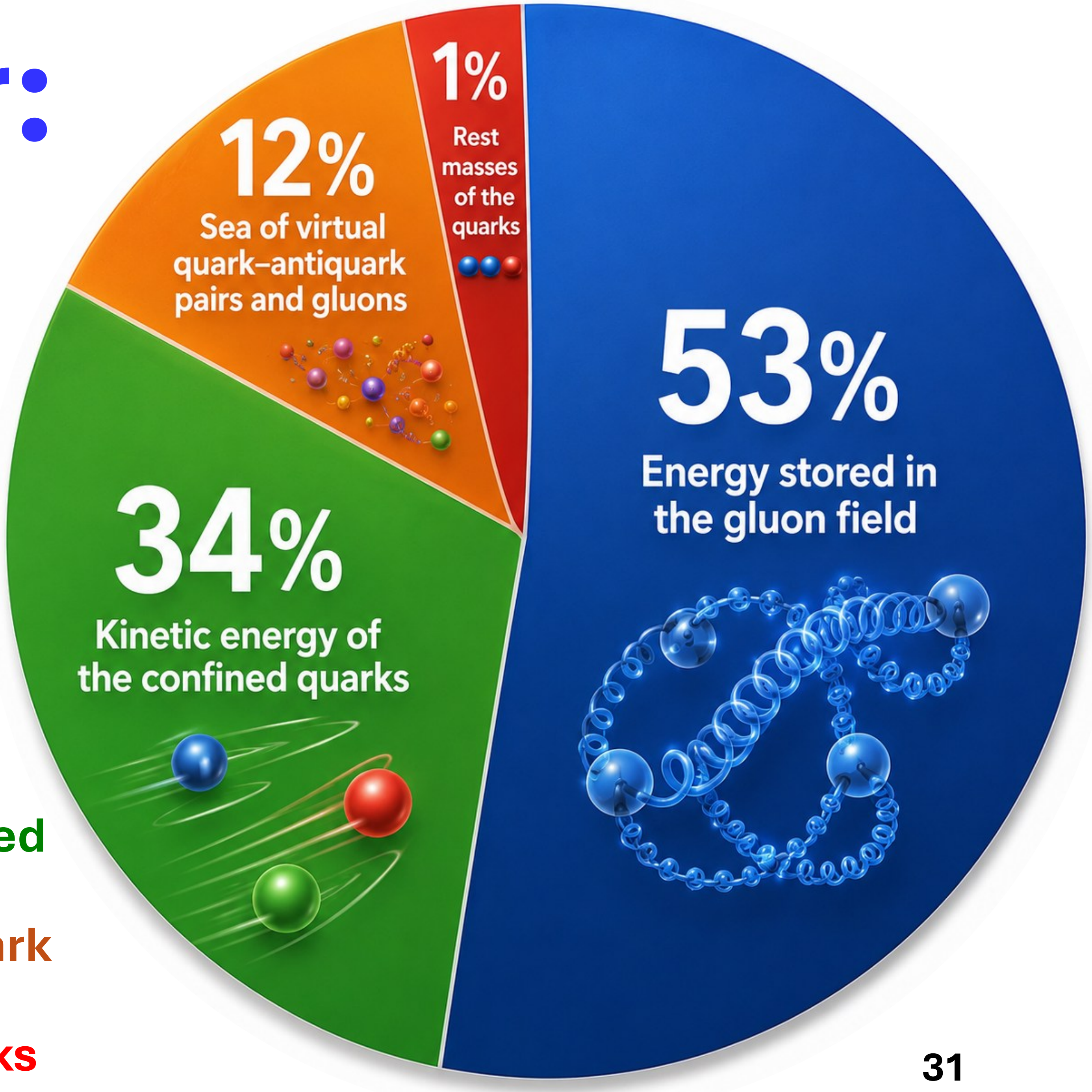
The Answer:

Most of the Mass Is Confined Energy

The Quantum State Machine predicts that the proton's and neutron's rest mass comes primarily from energy inside the bound state.

Approximate contributions:

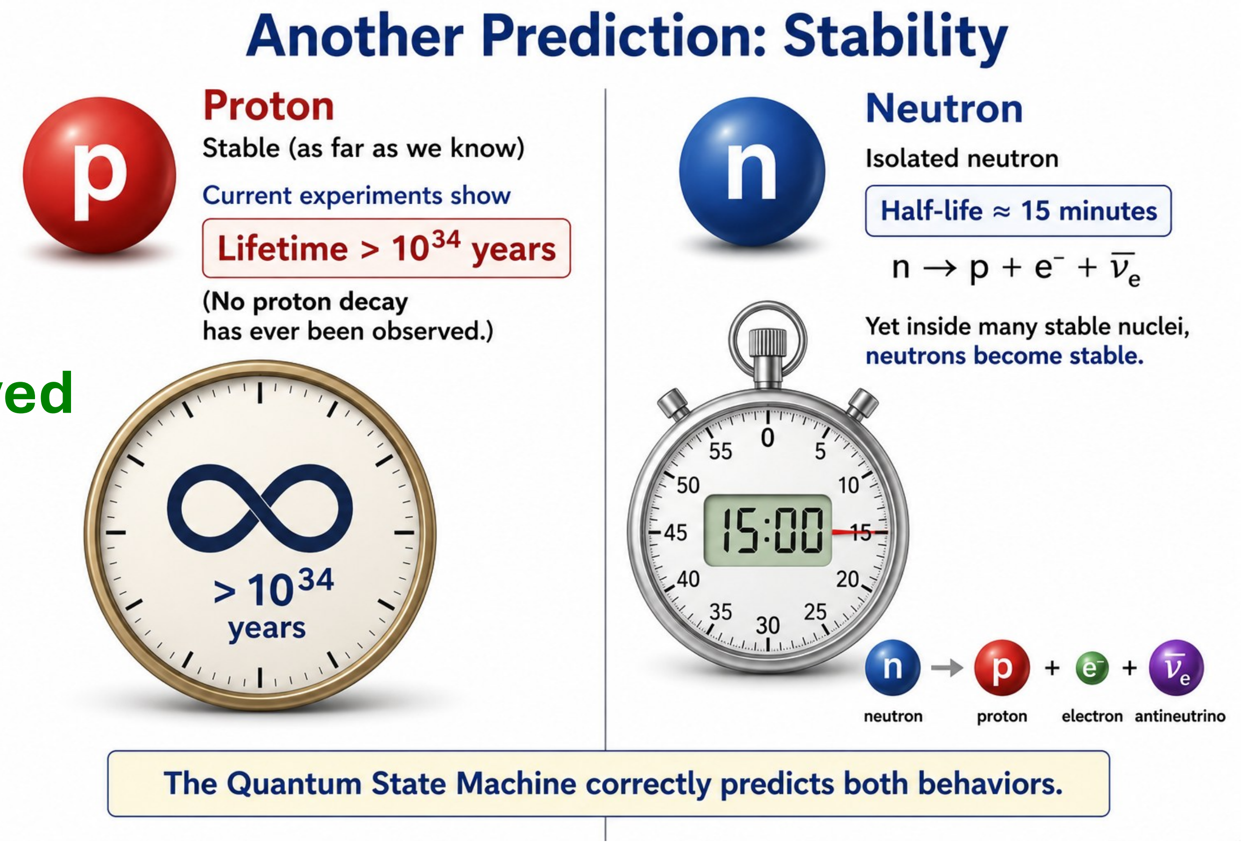
- 53% Energy stored in the gluon field
- 34% Kinetic energy of the confined quarks
- 12% Sea of virtual quark–antiquark pairs and gluons
- 1% Rest masses of the three quarks



Another Prediction: Stability

The Quantum State Machine predicts not only the masses of the proton and neutron—it also predicts their stability.

- Proton
  - ✓ Stable (as far as we know)
  - Current experiments show
  - Lifetime > 10^{34} years
  - No proton decay has ever been observed
- Neutron
  - Isolated neutron
  - Half-life ≈ 15 minutes
  - $n \to p + e^{-} + \bar{\nu}_e$
  - Yet inside many stable nuclei,
  - neutrons become stable.



A Process Theology Perspective

From Possibility to Structure

- **We have now seen that the Quantum State Machine predicts not only stable particles but also their measurable properties.**

Through the lens of Process Theology

- **Process Theology describes this as the continuing work of the Superjective Nature of God.**
- **The lure guides the quantum state through its process of becoming.**
- **The Born Rule reveals the mathematical pattern toward which the process of becoming has been guided.**
- **Repeated Actual Occasions gradually reveal that emergent order through experiment.**

The Process Theology Lens

Key Idea

The order we observe in nature emerges through countless Actual Occasions, yet it is already reflected in the probability distribution predicted by the Quantum State Machine.

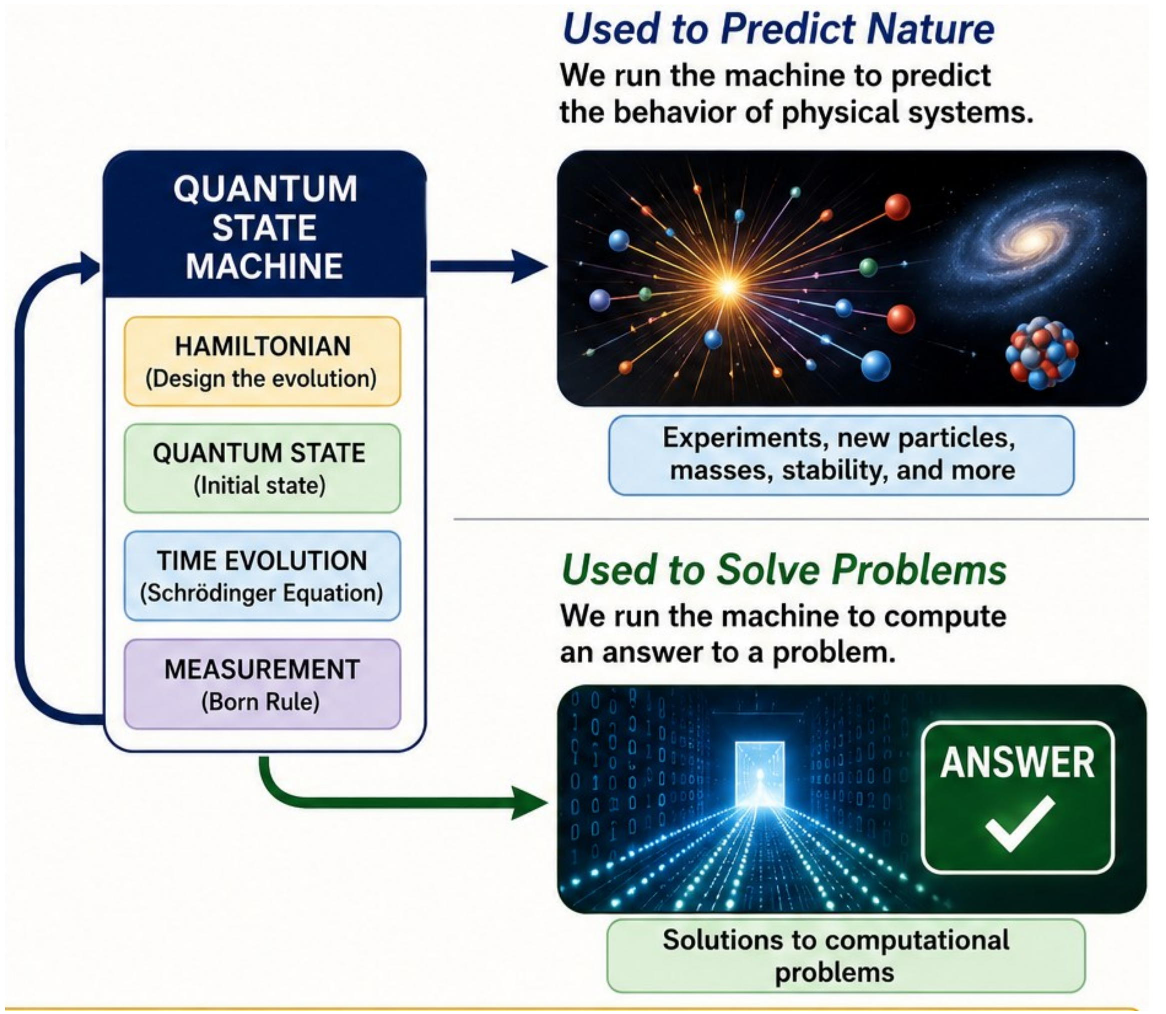
Can We Use the Quantum State Machine to Solve Problems?

So far we have used the Quantum State Machine to predict the behavior of nature.

- ✓ It predicts the results of physics experiments.
- ✓ It predicts the existence of new particles.
- ✓ It predicts their measurable properties.

Can the same mathematical framework be used for a completely different purpose?

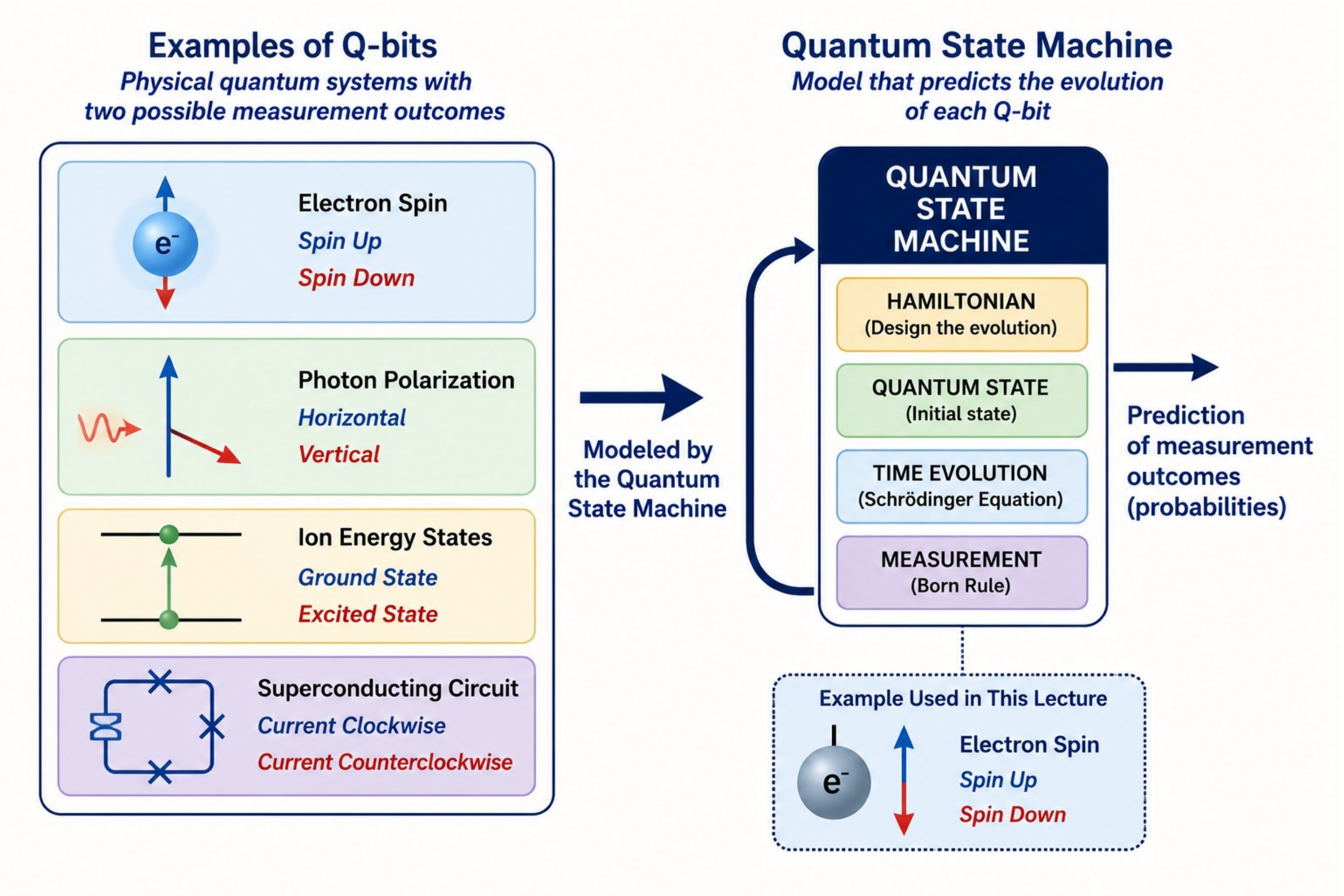
- Instead of predicting the outcome of a physics experiment...
- Can we use the Quantum State Machine to solve computational problems?



The Simplest Quantum System

The simplest quantum computer is built from physical quantum systems called q-bits.

- Examples include
  - ✓ An electron's spin
  - ✓ The polarization of a photon
  - ✓ The energy states of an ion
  - ✓ Superconducting electrical circuits
- The Quantum State Machine models the evolution of each q-bit.



The Quantum State of a Q-bit

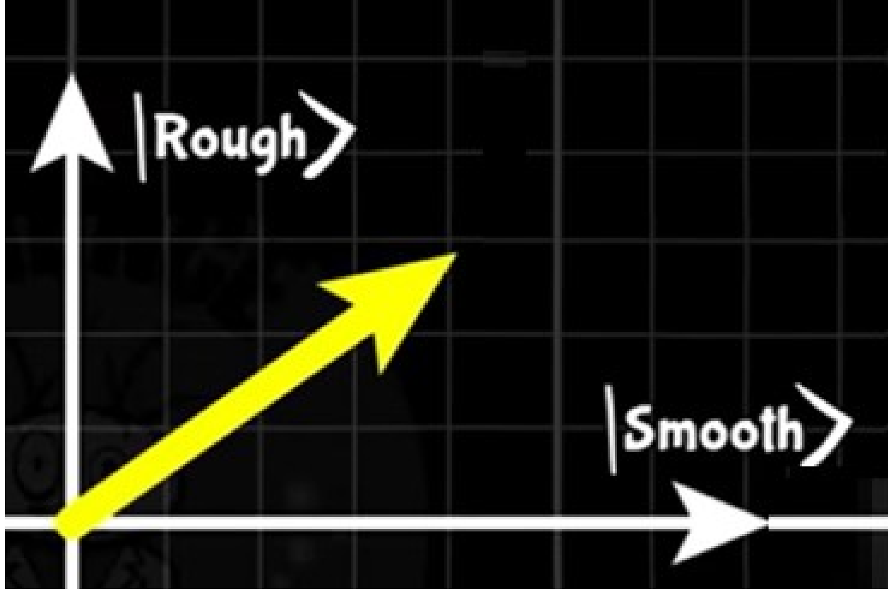
In Lecture 3 we learned an important lesson.

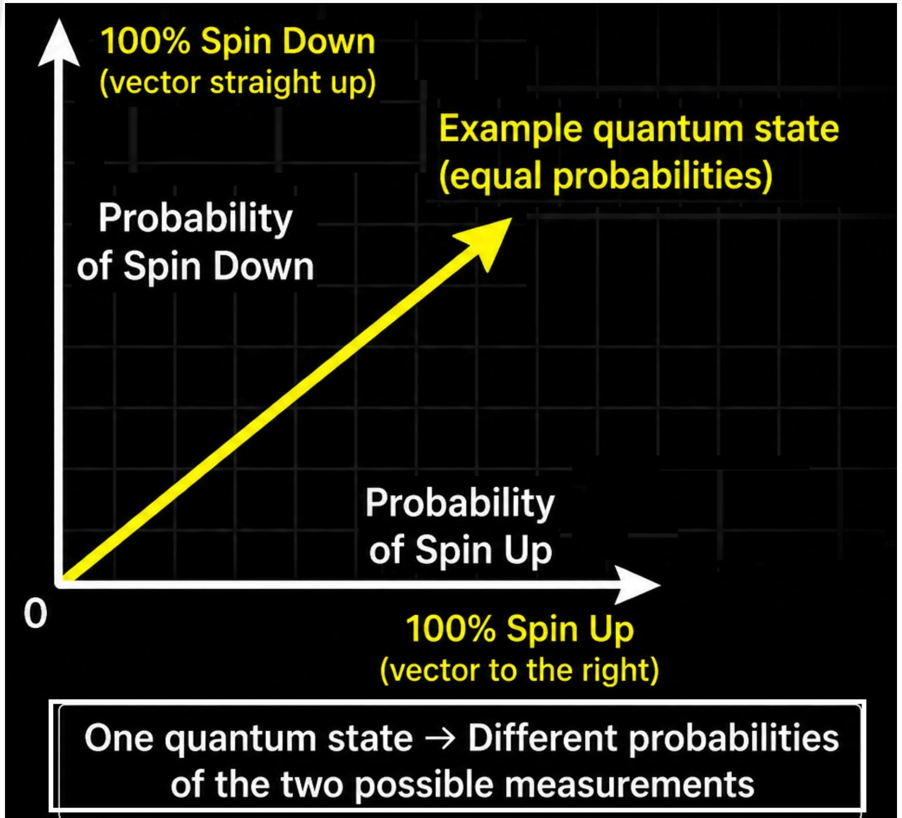
- ✓ A quantum system is always in one quantum state.
- ✓ It is not in several states at the same time.
- The quantum state determines the probabilities of the possible measurement outcomes.

For our q-bit, those measurement outcomes will be:

- ✓ Spin Up
- ✓ Spin Down

Next, let's see how we represent that quantum state.

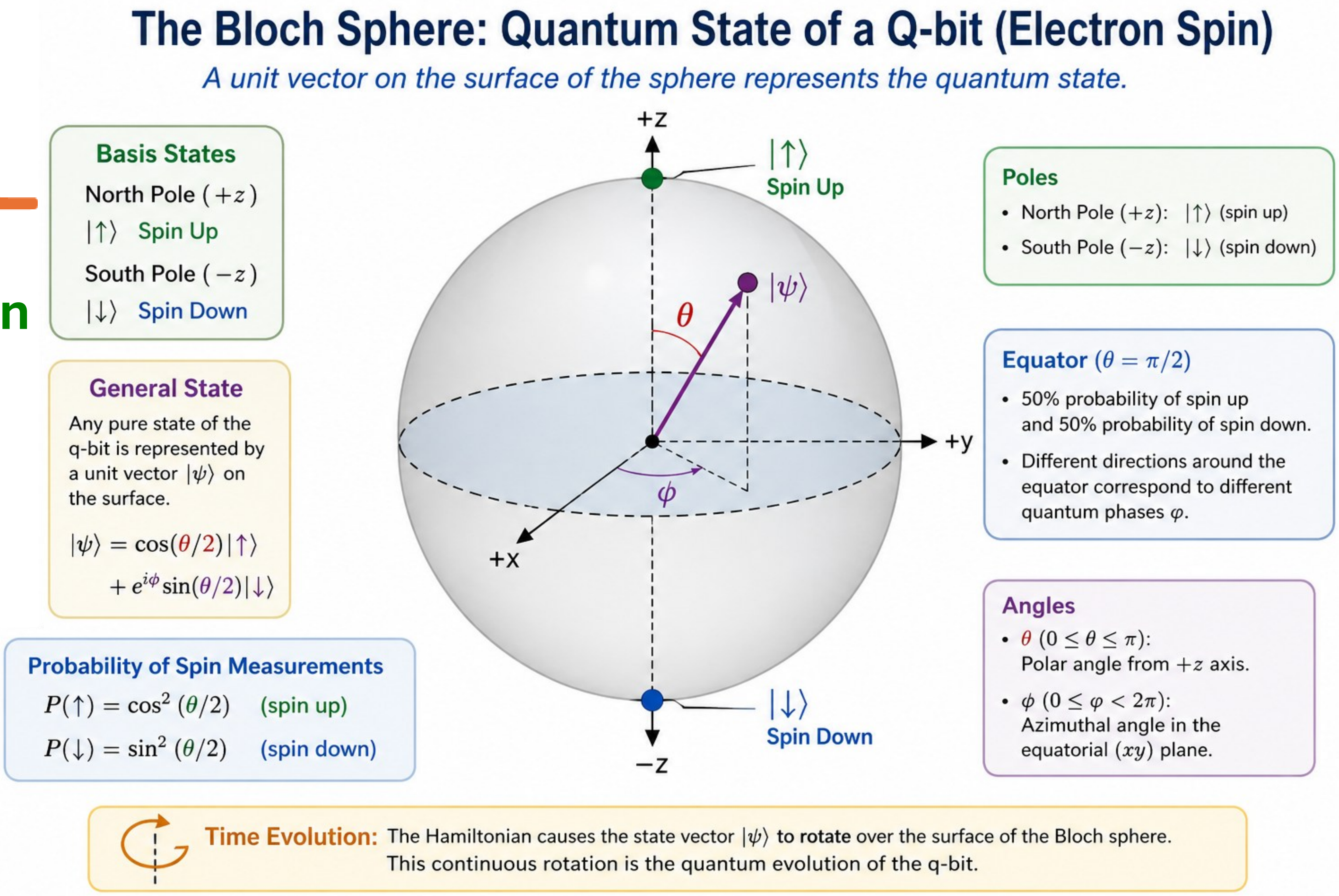




The Bloch Sphere: Visualizing a Q-Bit Quantum State

A q-bit can be formed from the two possible spin states of an electron.

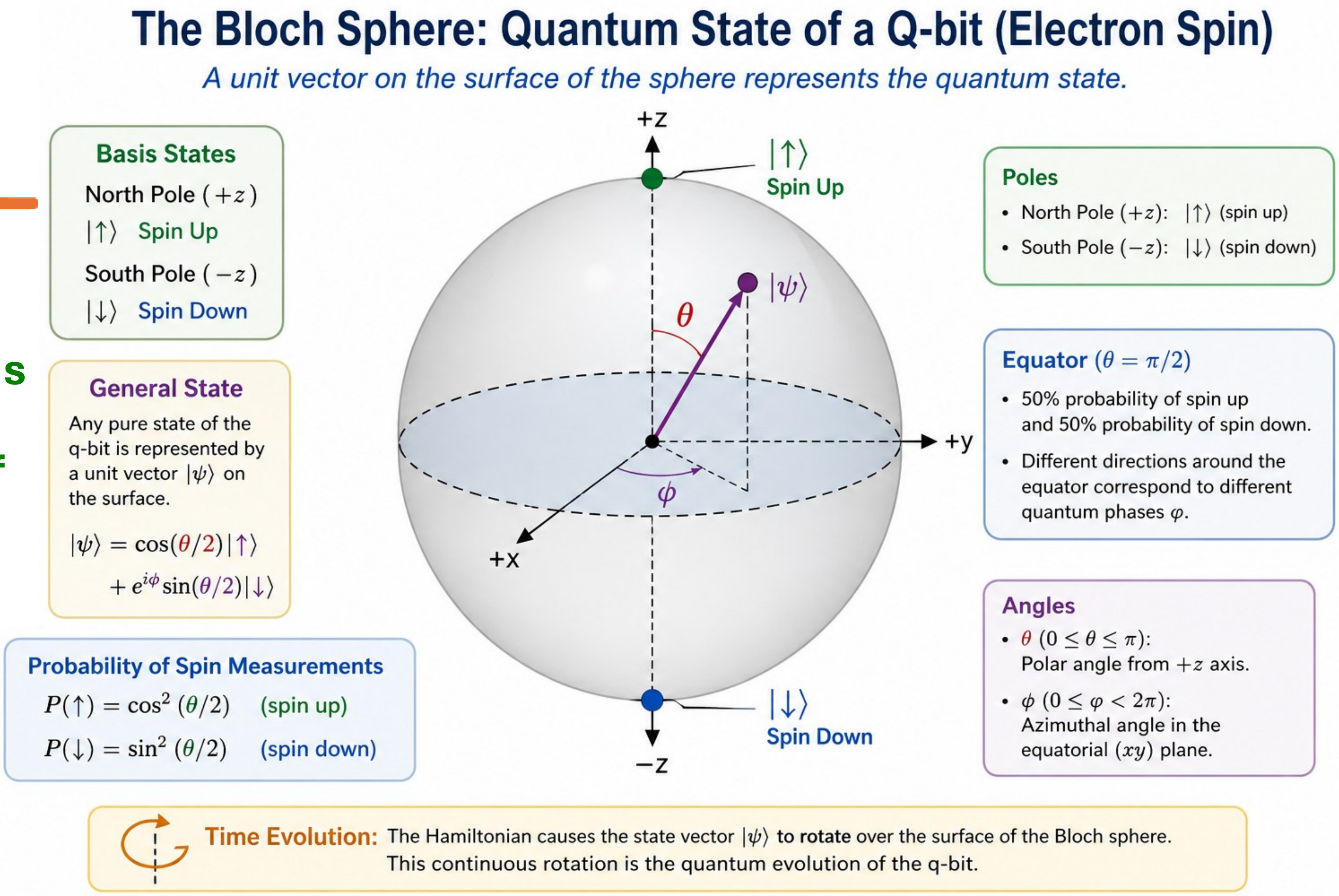
- **Basis States**
  - **North Pole → Spin Up (100% probability of measuring spin up)**
  - **South Pole → Spin Down (100% probability of measuring spin down)**



The Bloch Sphere: Visualizing a Q-Bit Quantum State

Most quantum states are not purely spin up or spin down.

- **Instead, the quantum state is represented by a unit vector extending from the center of the Bloch sphere to its surface.**
  - **Every point on the surface represents a different quantum state**
  - **The direction of the vector determines the probabilities of measuring spin up or spin down.**

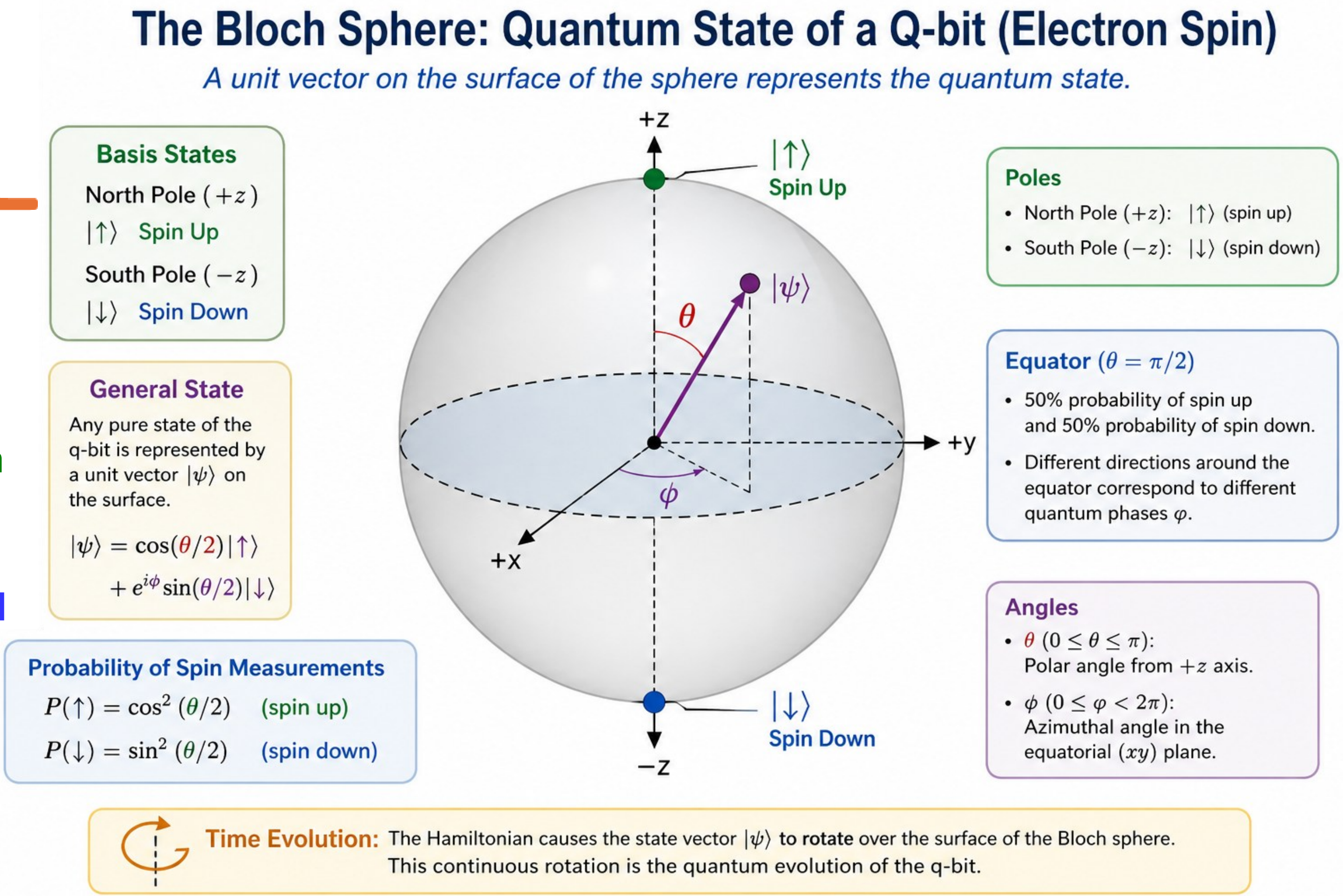


The Bloch Sphere: Visualizing a Q-Bit Quantum State

The Equator:

- **Vectors pointing toward the equator represent states with a 50% probability of spin up and a 50% probability of spin down.**
- **Different directions around the equator all have the same 50–50 probabilities, but they represent different quantum phases**

The Hamiltonian acts by continuously rotating this state vector over the surface of the Bloch sphere.



One Classical Bit vs. One Q-bit

Classical Bit

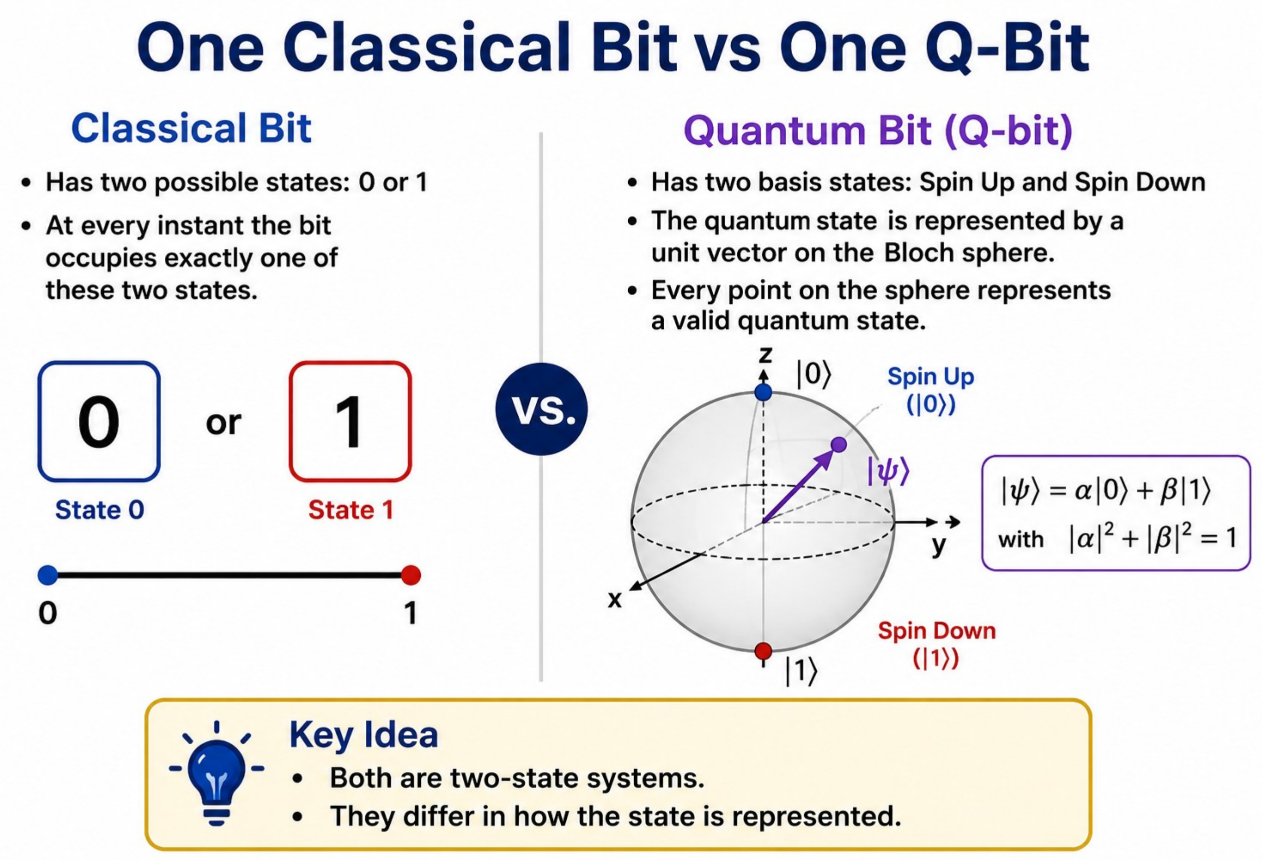
- Has two possible states: 0 or 1
- At every instant the bit occupies exactly one of these two states.

Quantum Bit (Q-bit)

- Has two basis states: Spin Up and Spin Down
- The quantum state is represented by a unit vector on the Bloch sphere.
- Every point on the sphere represents a valid quantum state.

Key Idea

- Both are two-state systems.
- They differ in how the state is represented.



How the State Evolves

Classical Computer

- A classical bit changes state through logic gates.

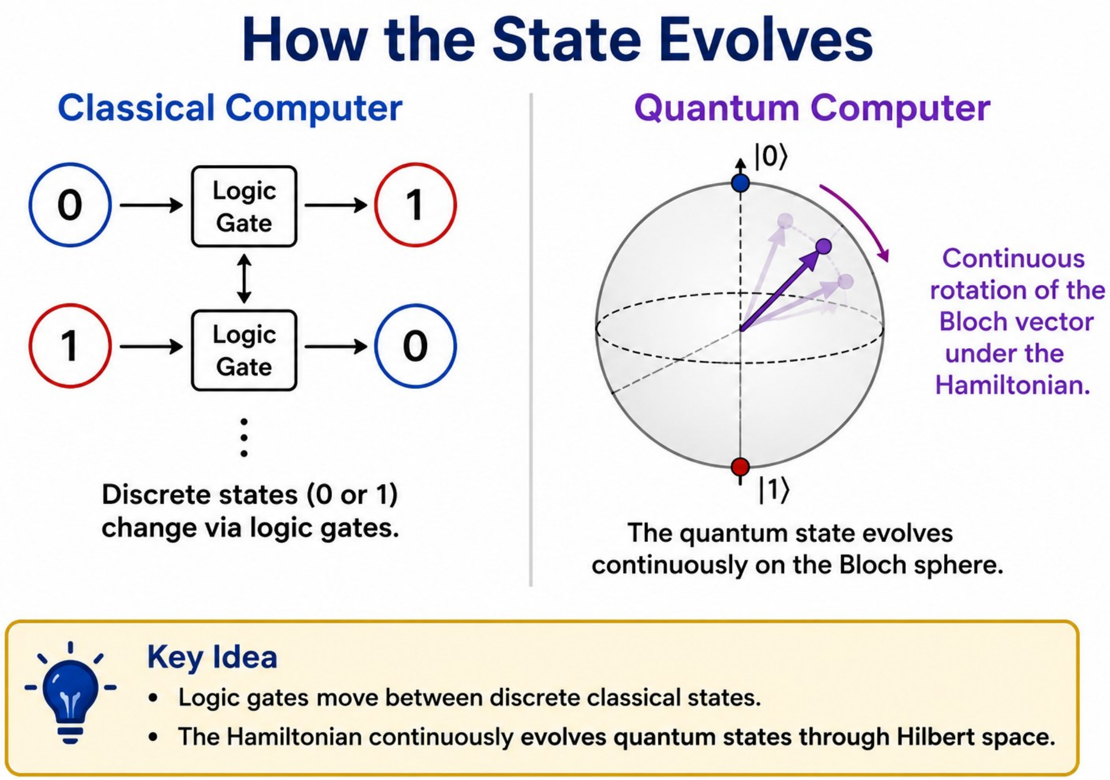
Examples:

- 0 → 0
- 0 → 1
- 1 → 0
- 1 → 1

Each gate performs one simple logical operation.

Quantum Computer

- A q-bit evolves according to the Hamiltonian.
- The Hamiltonian continuously changes the quantum state.
- For one q-bit this evolution can be visualized as a continuous rotation of the Bloch vector.



Key Idea

Logic gates move between discrete classical states.

The Hamiltonian continuously evolves quantum states through Hilbert space.

Both the Classical and Quantum Computer are State Machines

Classical Computer

State

- Register containing N bits

Evolution Rule

- Logic gates (Transistors)

Output

- Read the bit pattern directly

Quantum Computer

State

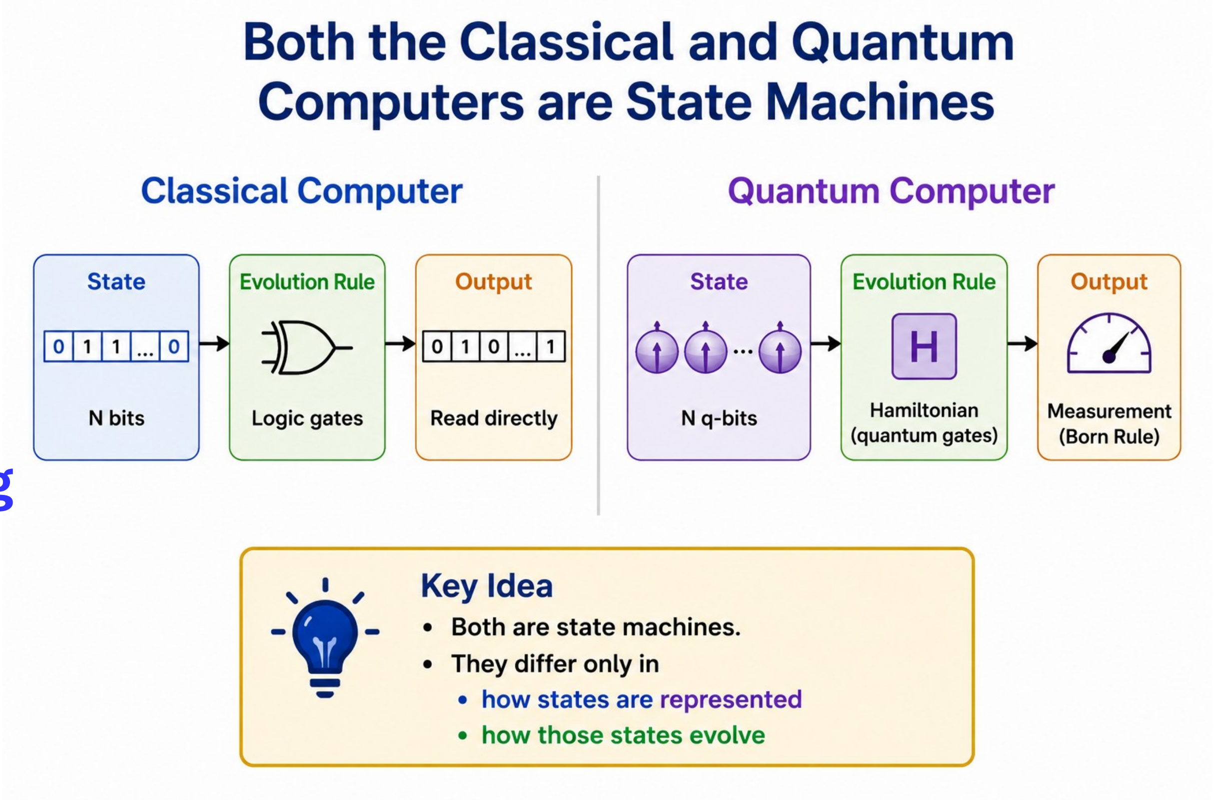
- Register containing N q-bits

Evolution Rule

- Hamiltonian (implemented using quantum gates)

Output

- Measurement (Born Rule)



Both the classical computer and the quantum computer are state machines that only in:

- how states are represented
- how those states evolve

If Both Have the Same Number of States, Why Is Quantum Computing Different?

Classical Computer

- An N-bit register has
- 2^N possible states

Examples

- 1 bit → 2 states
- 4 bits → 16 states
- 32 bits → 4,294,967,296 states

However,

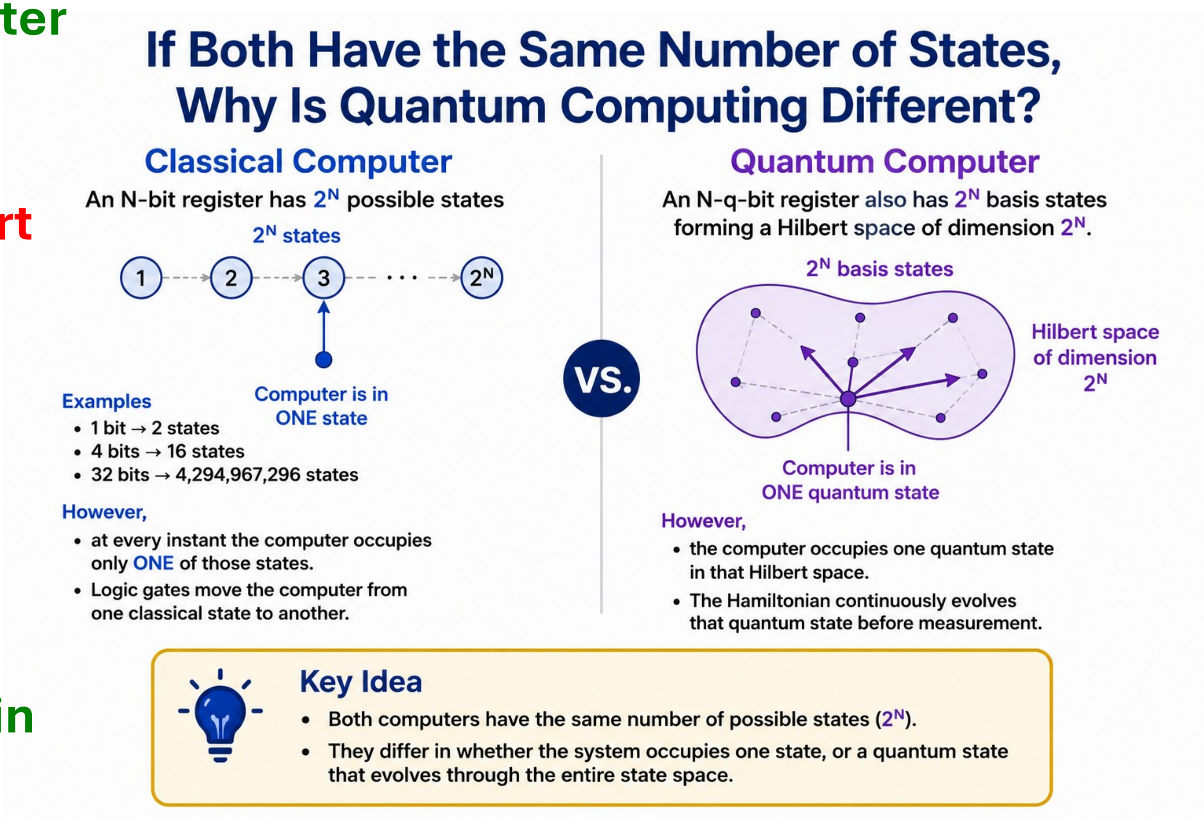
- at every instant the computer occupies only ONE of those states.
- Logic gates move the computer from one classical state to another.

Quantum Computer

- An N-q-bit register also has
- 2^N basis states
- forming a Hilbert space of dimension 2^N.

However,

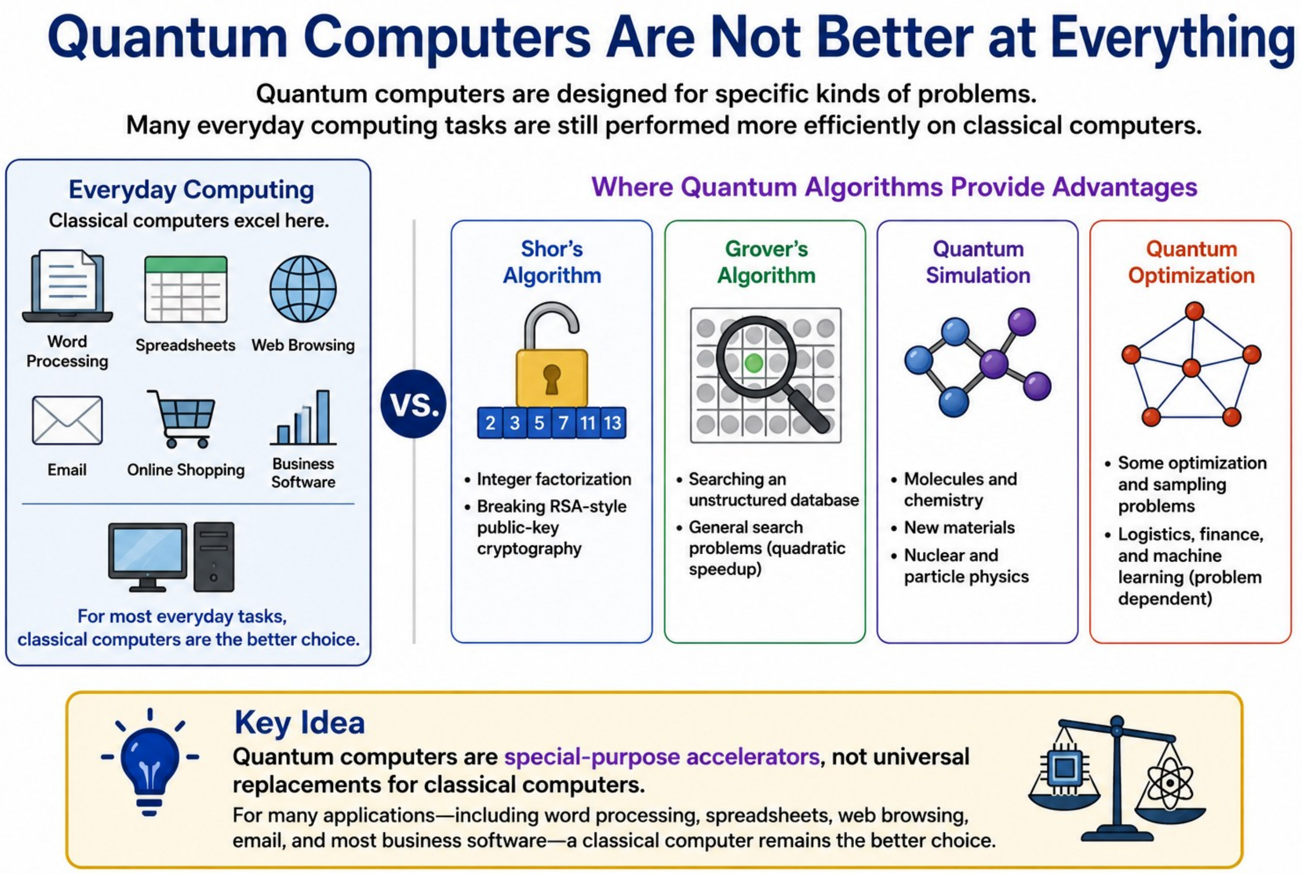
- At every instant the quantum computer occupies one quantum state in that Hilbert space.
- The Hamiltonian continuously evolves that quantum state before measurement.



Quantum Computers Are Not Better at Everything

Quantum computers are designed for specific kinds of problems.

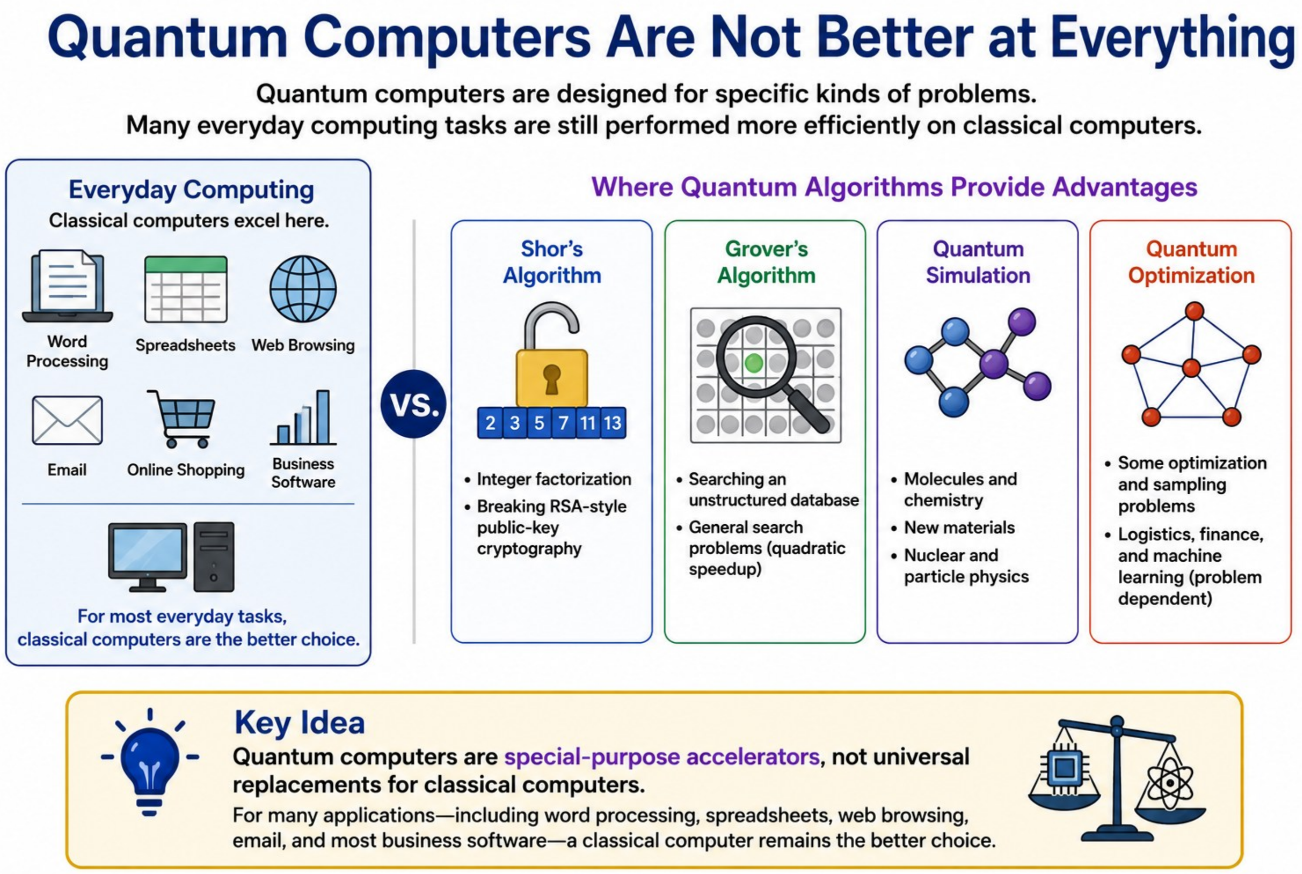
- Many everyday computing tasks are still performed more efficiently on classical computers.



Quantum Computers Are Not Better at Everything

Examples where quantum algorithms provide significant advantages include:

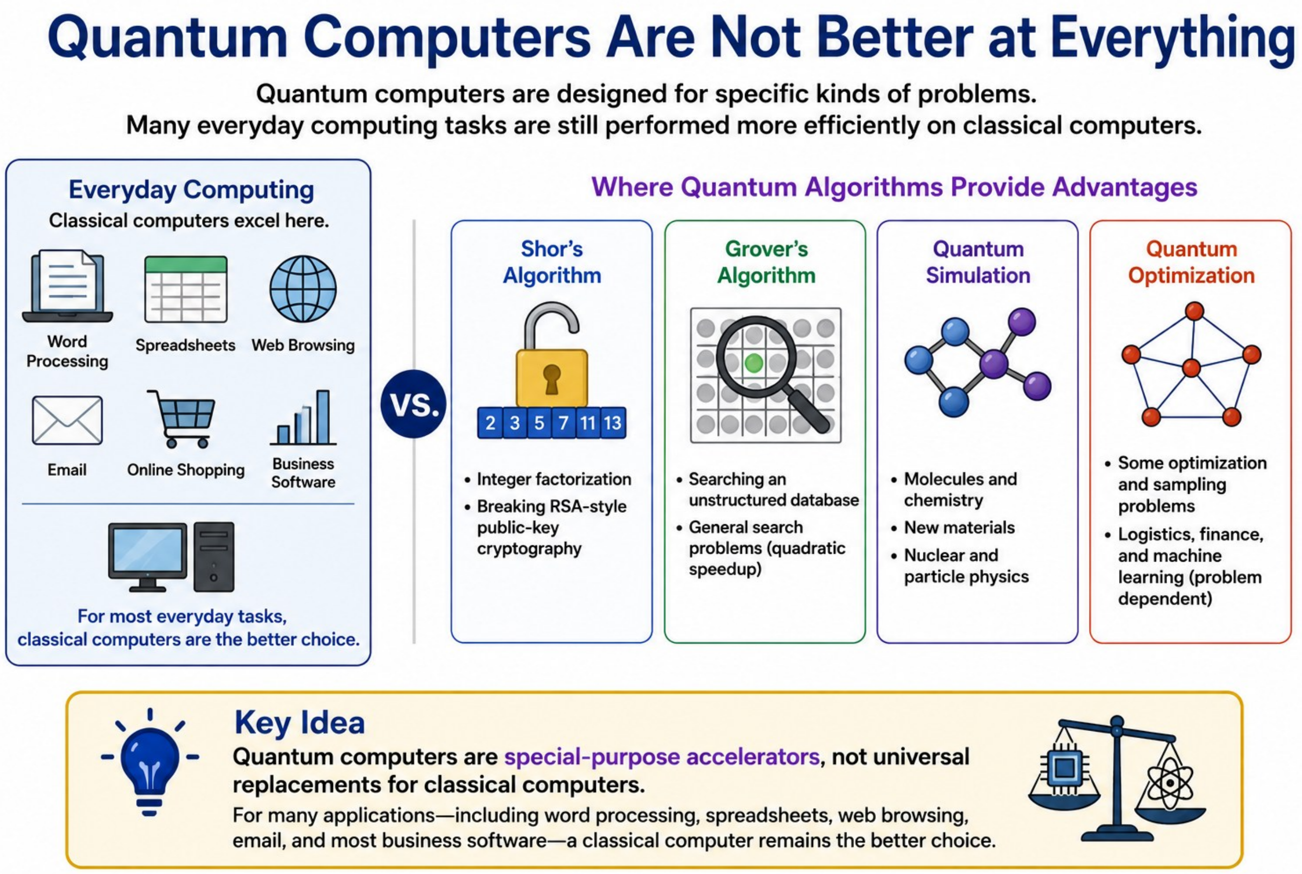
- **Shor's Algorithm**
  - Integer factorization
  - Breaking RSA-style public-key cryptography
- **Grover's Algorithm**
  - Searching an unstructured database
  - General search problems (quadratic speedup)
- **Quantum Simulation**
  - Molecules and chemistry
  - New materials
  - Nuclear and particle physics
- **Quantum Optimization**
  - Some optimization and sampling problems
  - Logistics, finance, and machine learning (problem dependent)



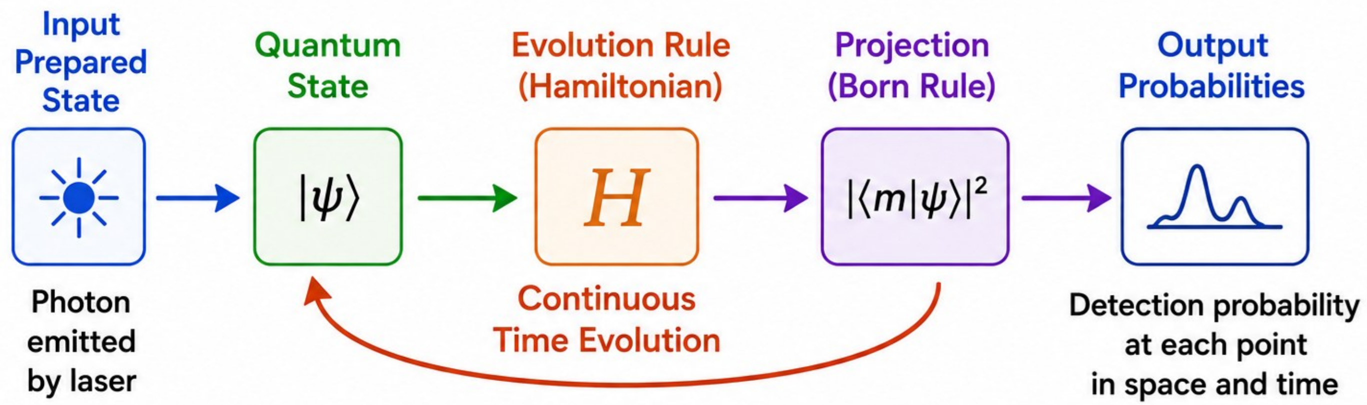
Quantum Computers Are Not Better at Everything

Key Idea

- Quantum computers are special-purpose accelerators, not universal replacements for classical computers.
- For many applications—including word processing, spreadsheets, web browsing, email, and most business software—a classical computer remains the better choice.



Where Does the Quantum Advantage Come From?



Both computers have exponentially many possible states.

- The difference is not the number of states.
- The difference is how those states evolve.

Classical Computer

- Logic gates move from one classical state to another.
- The programmer designs the logic by writing computer code.

Quantum Computer

- The Hamiltonian evolves the entire quantum state coherently through Hilbert space.
- The programmer designs the Hamiltonian (using quantum gates) so that useful probability amplitudes reinforce one another
- Unwanted probability amplitudes cancel through interference
- Only after this evolution is complete is the quantum state measured.

Key Idea

The power of quantum computing comes from controlling the evolution of the quantum state before measurement.

One Mathematical Framework

The same quantum formalism can be used to describe

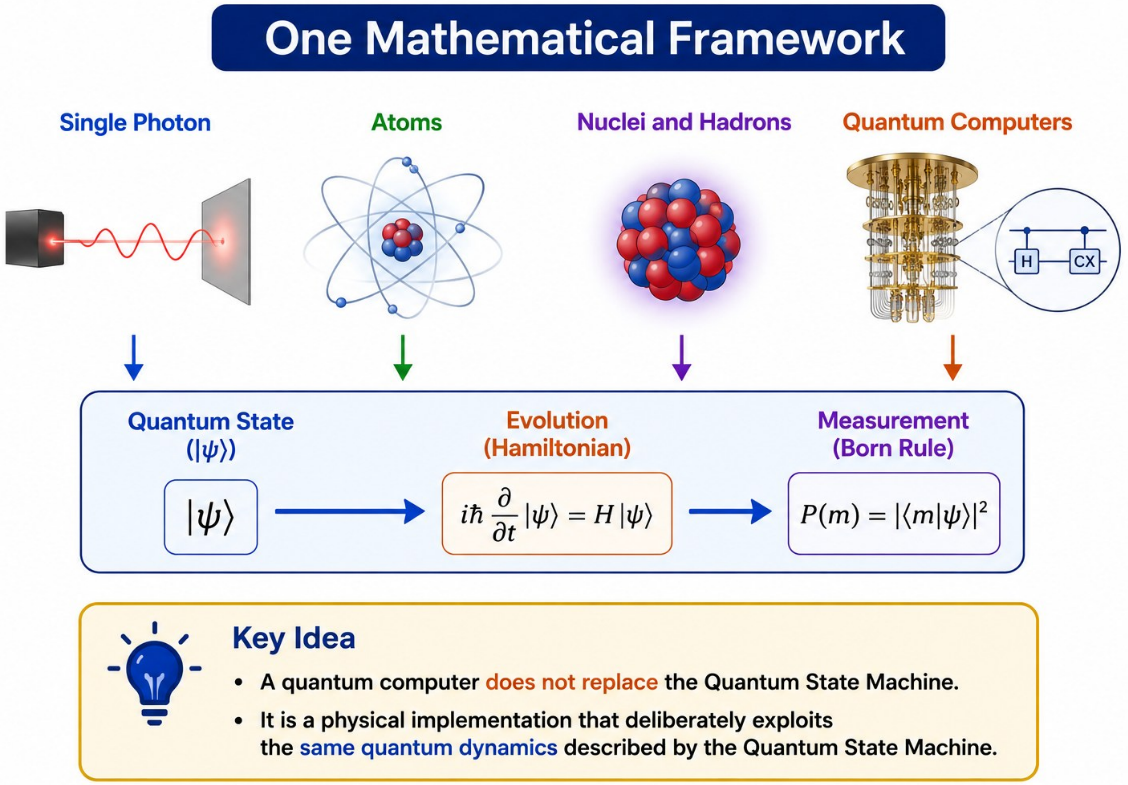
- the evolution of a single photon,
- the formation of atoms, nuclei, and hadrons,
- and the operation of quantum computers.

In every case,

- the Hamiltonian governs the evolution of the quantum state.
- The Born Rule connects the quantum state to experimental observations.

Key Idea

- A quantum computer does not replace the Quantum State Machine.
- It is a physical implementation that deliberately exploits the same quantum dynamics described by the Quantum State Machine.



A Process Theology Perspective

One Lure...Many Expressions

Throughout this lecture we have seen one mathematical framework applied to

- photons
- mesons and baryons
- nuclei
- quantum computers

From a Process Theology perspective,

- The Superjective Nature of God is the theological description of the same continual lure that the Hamiltonian mathematically describes.
- The evolving quantum state represents the process of becoming.
- The Born Rule reveals the emergent pattern toward which that becoming is being guided.
- Individual observations are Actual Occasions that progressively reveal that pattern.

The Process Theology Lens

Key Idea

One mathematical framework...
One process of becoming...
One continual lure toward an emergent order.

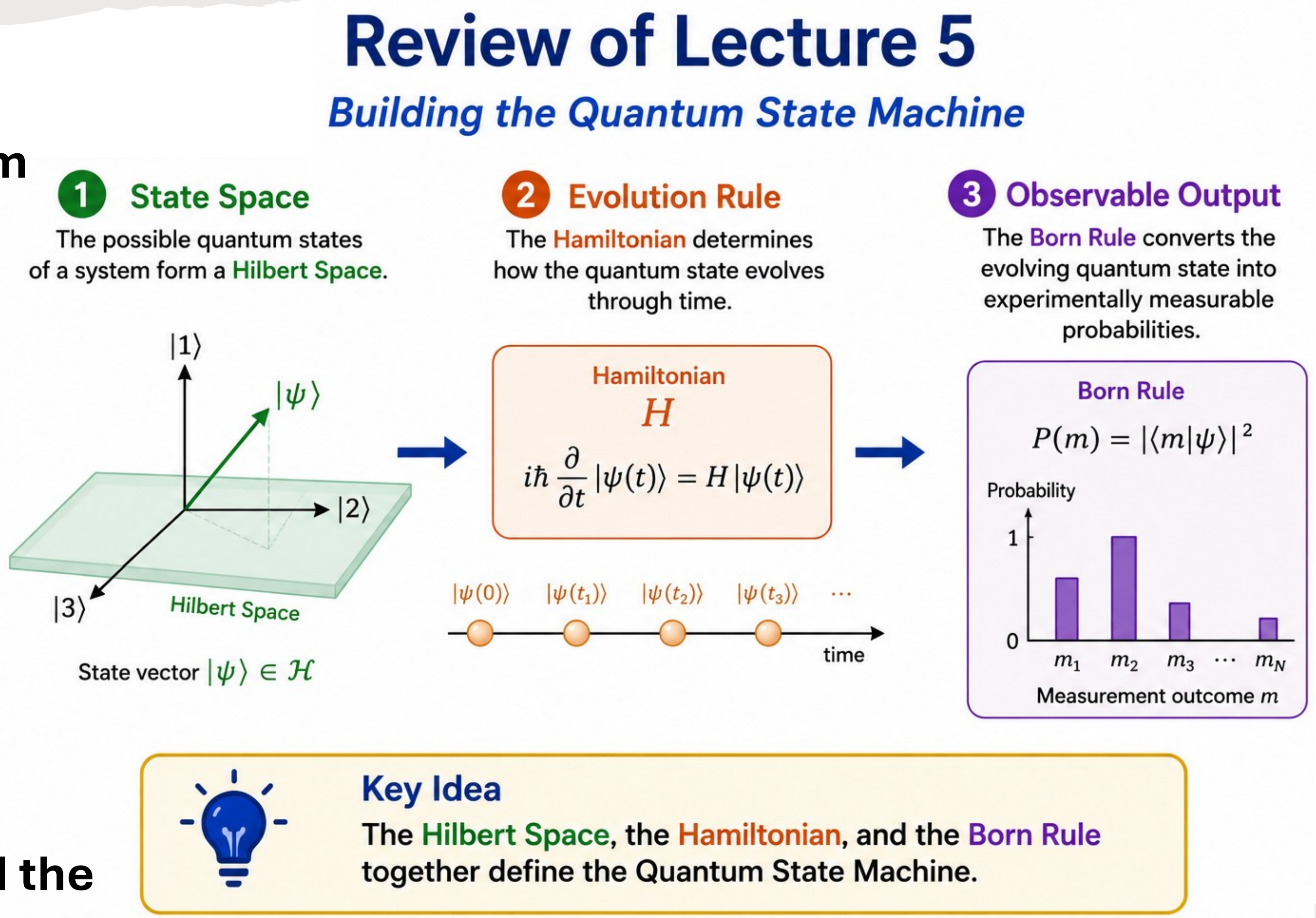
Lecture 5 Review

Building the Quantum State Machine

1. **State Space**
   - **The possible quantum states of a system form a Hilbert Space.**
2. **Evolution Rule**
   - **The Hamiltonian determines how the quantum state evolves through time.**
3. **Observable Output**
   - **The Born Rule converts the evolving quantum state into experimentally measurable probabilities.**

Key Idea

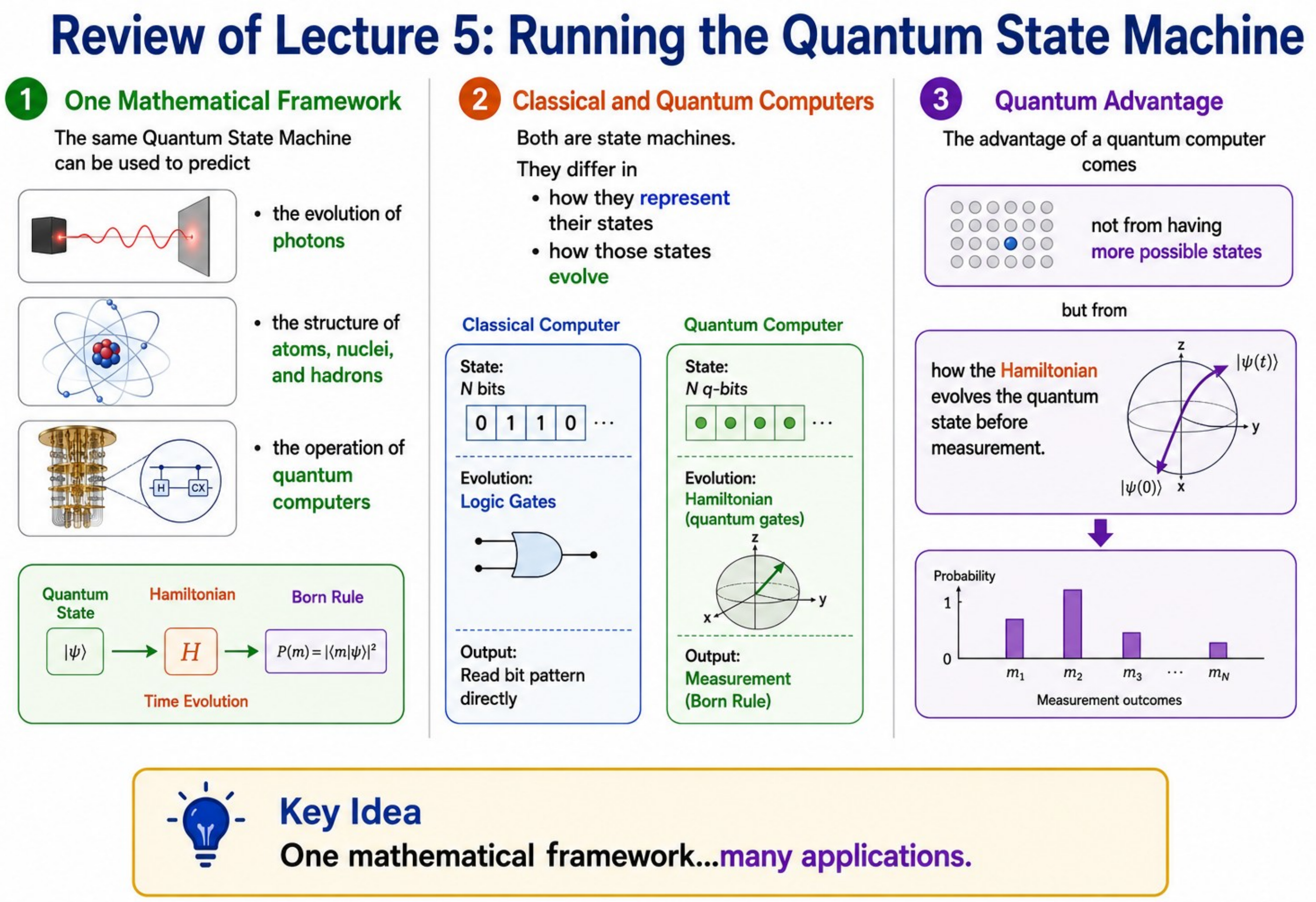
- **The Hilbert Space, the Hamiltonian, and the Born Rule together define the Quantum State Machine.**



Lecture 5 Review

Running the Quantum State Machine

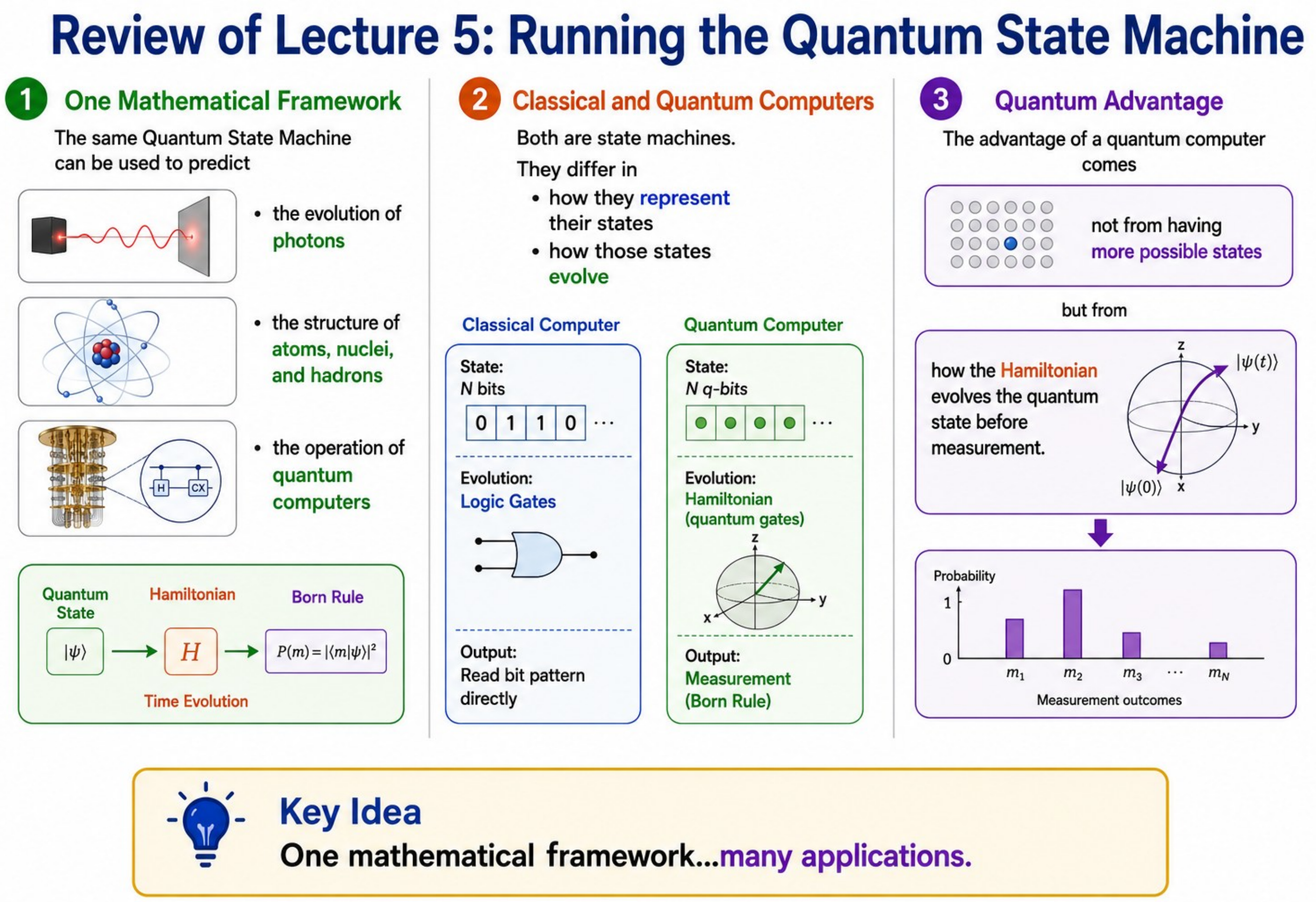
1. One Mathematical Framework
   - The same Quantum State Machine can be used to predict
     - the evolution of photons
     - the structure of atoms, nuclei, and hadrons
     - the operation of quantum computers.



Lecture 5 Review

Running the Quantum State Machine

2. Classical and Quantum Computers
   - Both are state machines that differ in:
     - How they represent their states
     - How those states evolve.



Lecture 5 Review

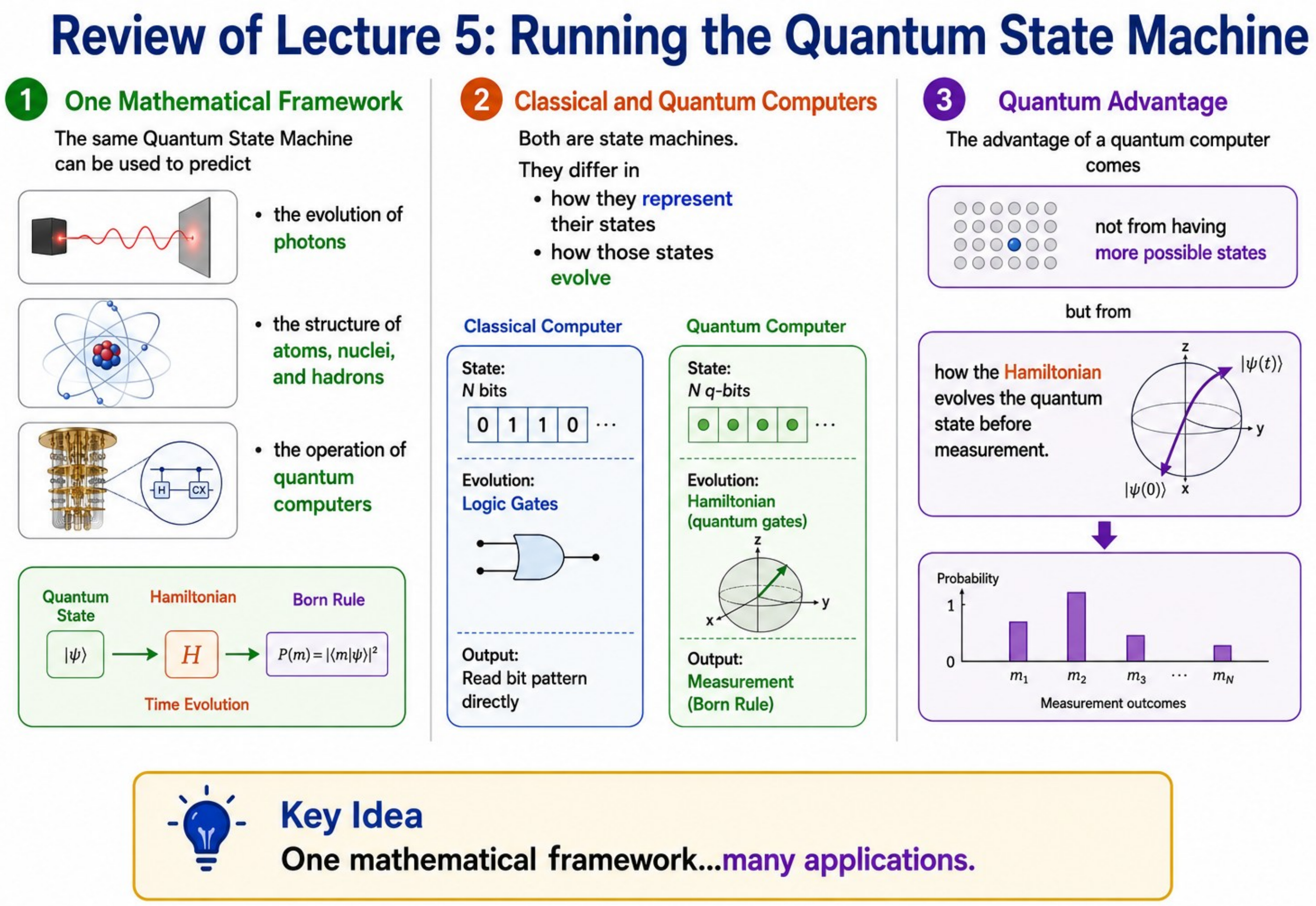
Running the Quantum State Machine

3. Quantum Advantage

- The advantage of a quantum computer comes:
    - Not from having more possible states

But from

- How the Hamiltonian evolves the quantum state before measurement.



Key Idea

One mathematical framework...

many applications.

Next Time...

The Infamous Single-Slit Experiment

For more than one hundred years, physicists have explained the spreading of light passing through a narrow slit using

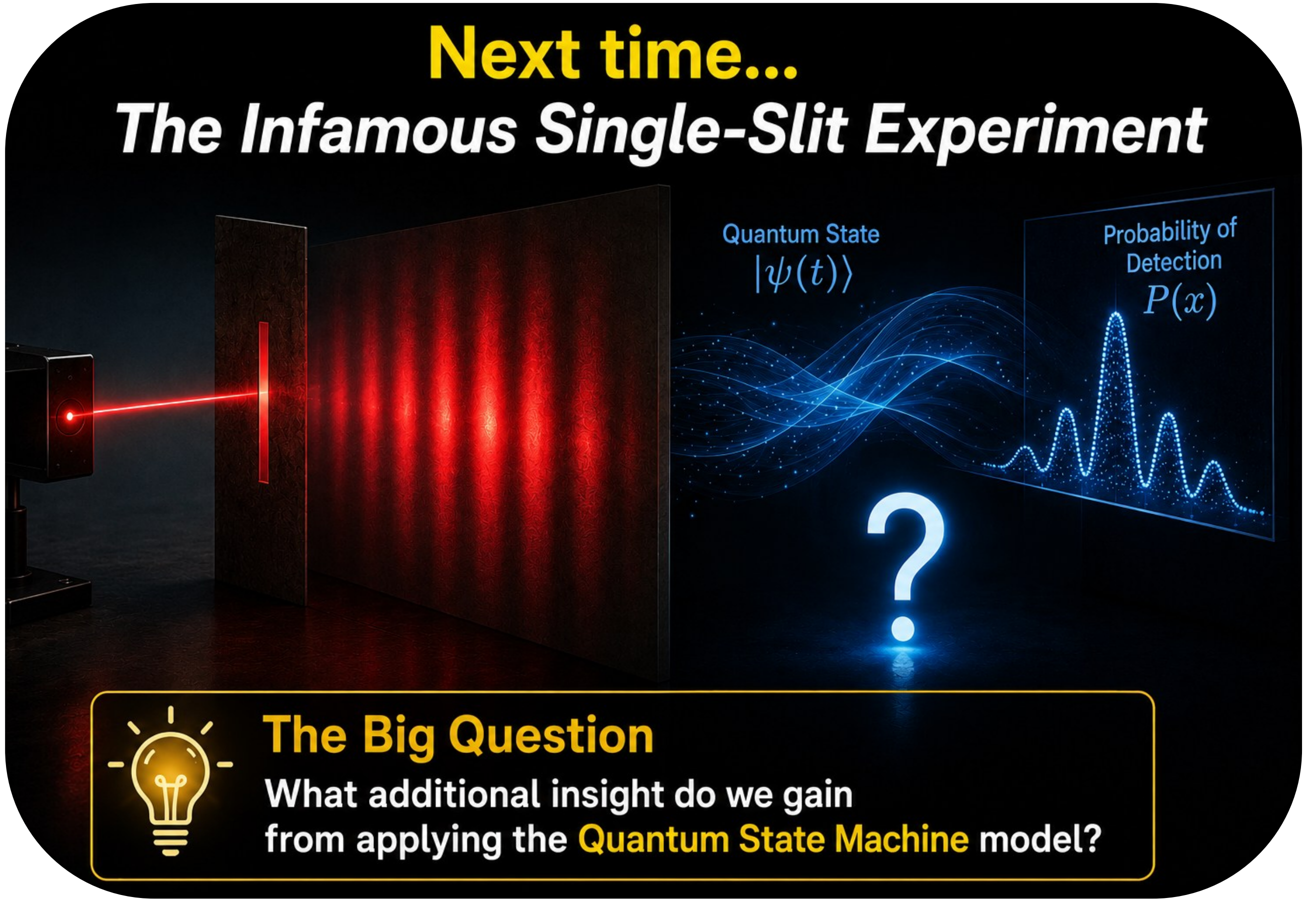
- Classical Electromagnetism

and

- the Uncertainty Principle.

These explanations correctly predict the observed probability distribution.

But are they telling the whole story?



Next Time...

The Infamous Single-Slit Experiment

Next time we will compare three different descriptions of the same experiment.

Classical Electromagnetism

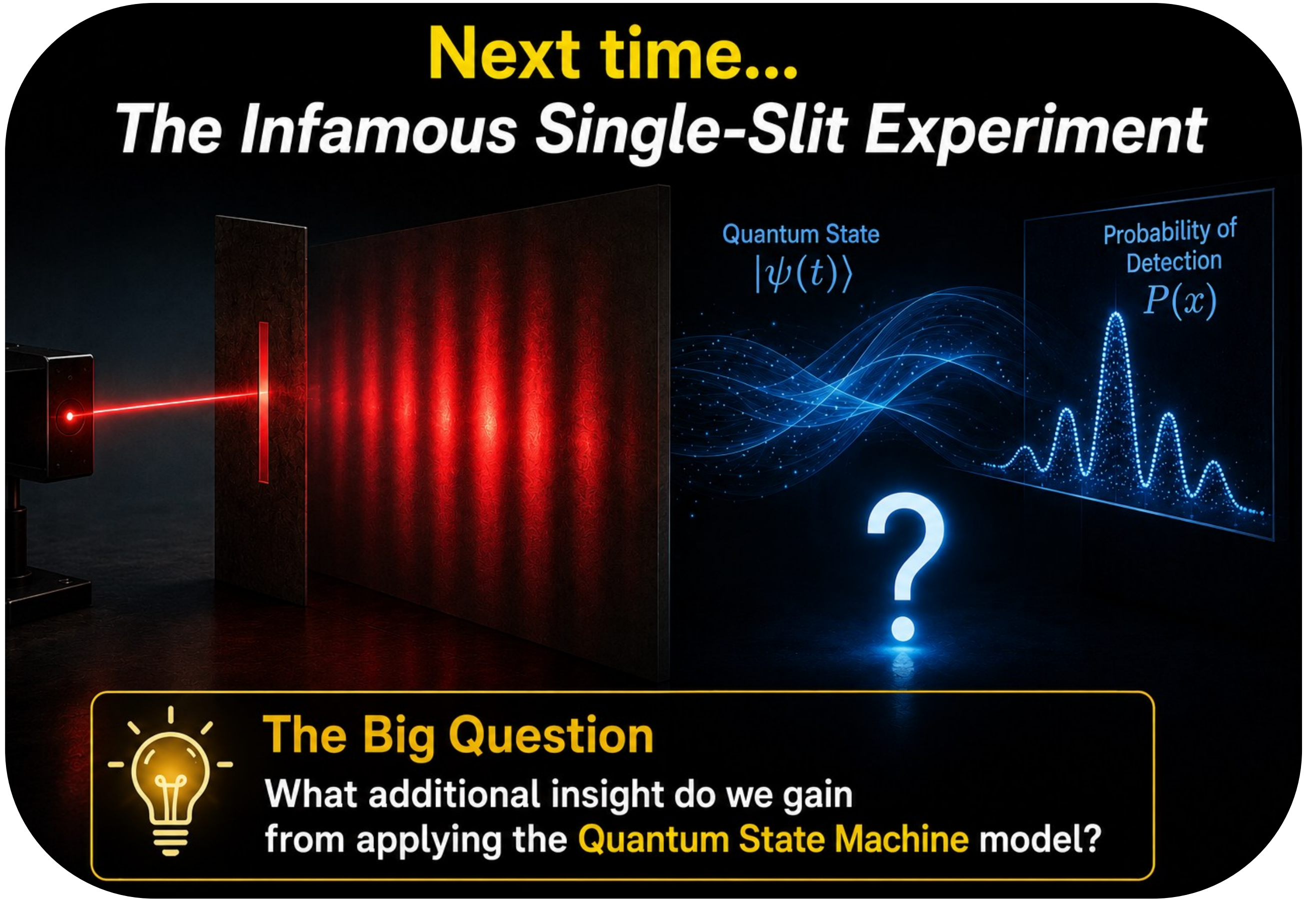
- Predicts the intensity distribution of the light wave.

The Uncertainty Principle

- Predicts the probability distribution for detecting photons.

The Quantum State Machine

- Predicts the complete quantum evolution that gives rise to the probability distribution.

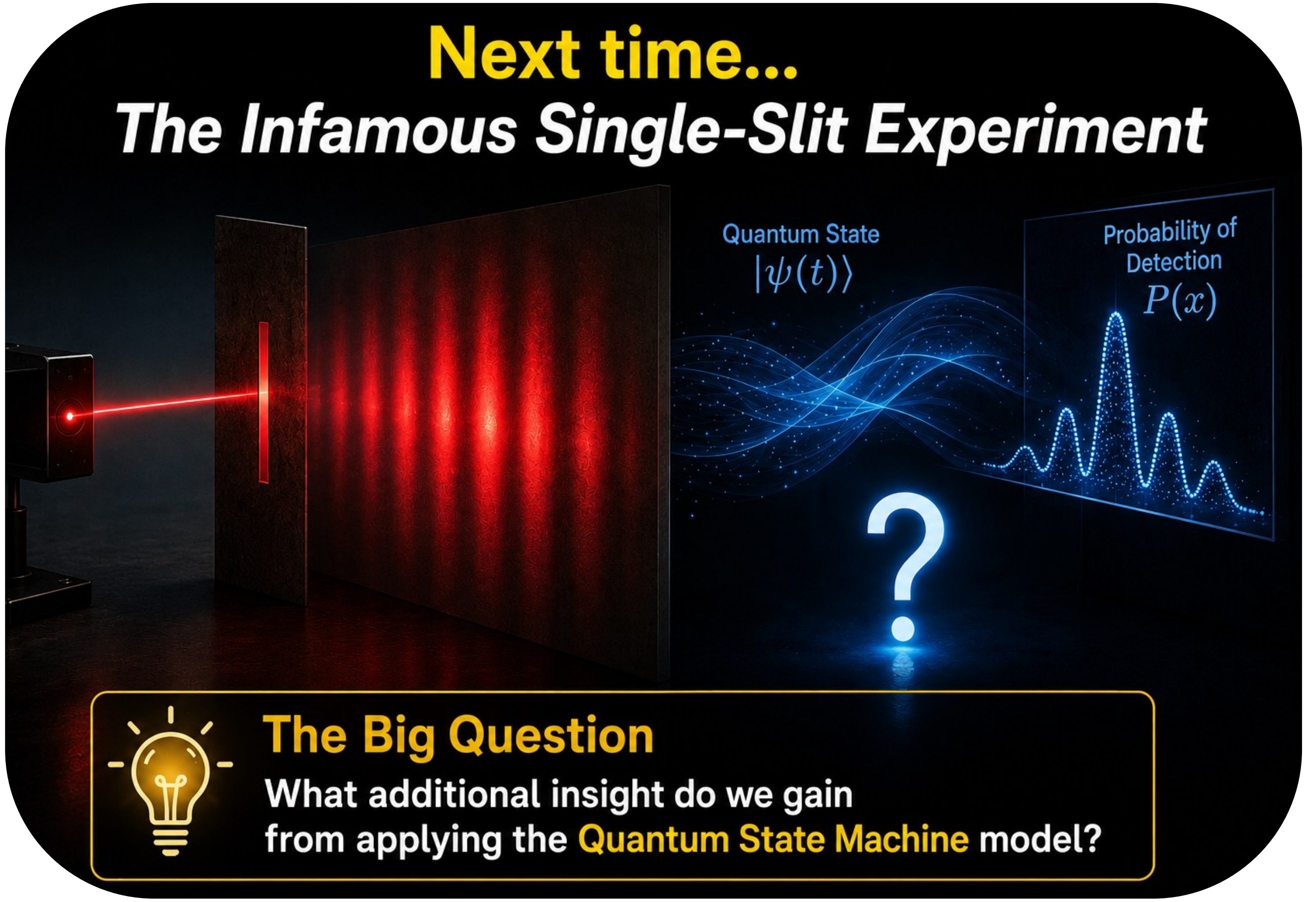


Next Time...

The Infamous Single-Slit Experiment

The Big Question

- What additional insight do we gain by applying the Quantum State Machine model itself?




"That's all Folks!"
Isberg©