A Very Short Introduction to

Particle Physics

What have we discovered so far?

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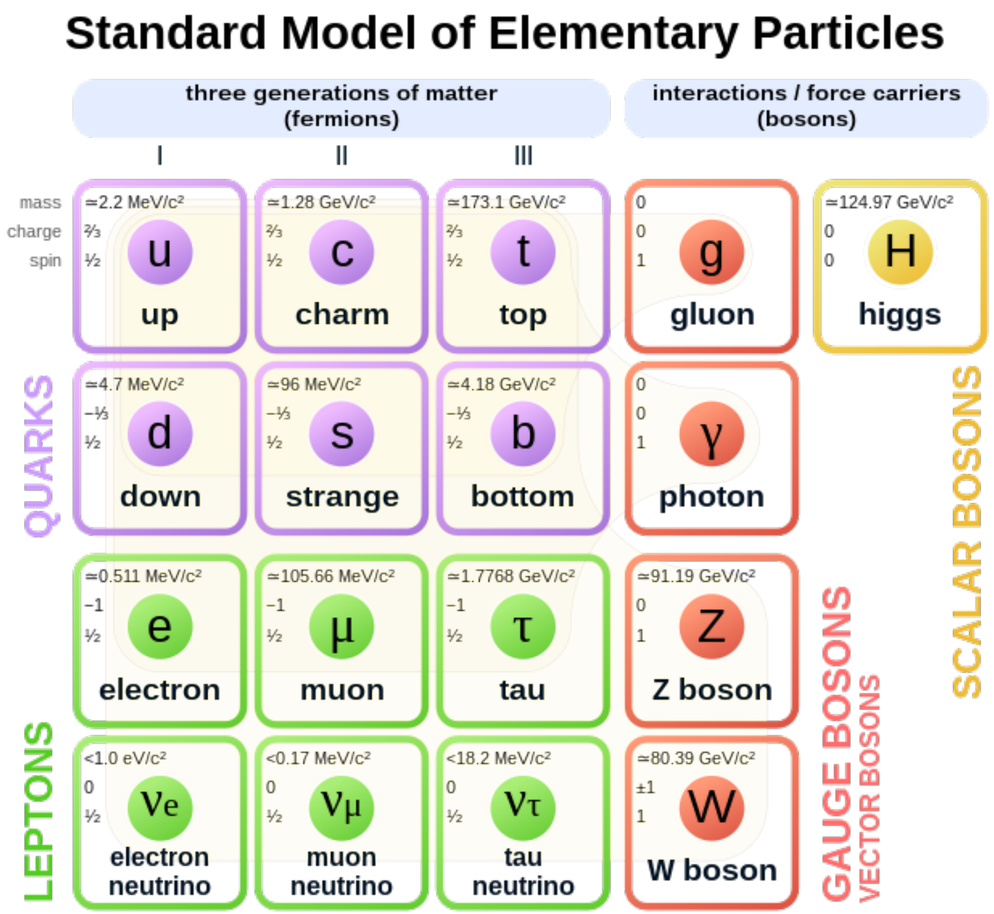
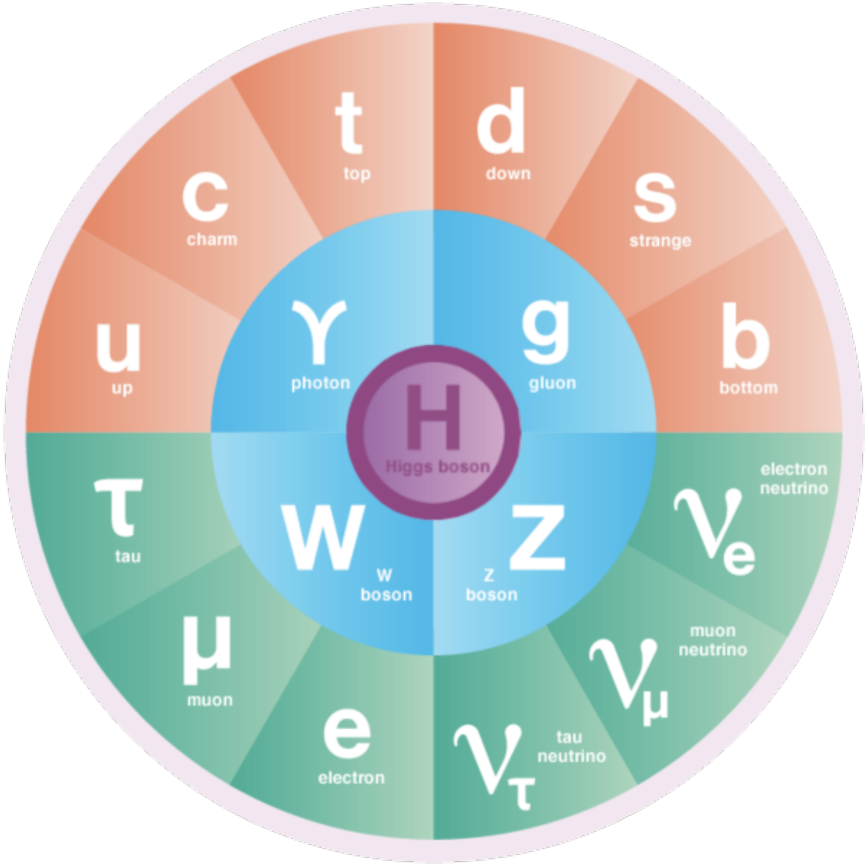
The Standard Model of Particle Physics



https://en.wikipedia.org/wiki/Standard_Model

What have we discovered so far?

The Standard Model of Particle Physics



https://www.symmetrymagazine.org/standard-model/

What more?

Beyond The Standard Model

- Supersymmetry
- Neutrino Oscillation
- Dark Energy and Dark Matter
- Matter-antimatter asymmetry
- Grand Unified Theory
- Theory of Everything
- etc.

These will be explained later in Saturday’s sessions.

What exactly is particle?

What exactly is particle?

In classical physics

Light is wave.

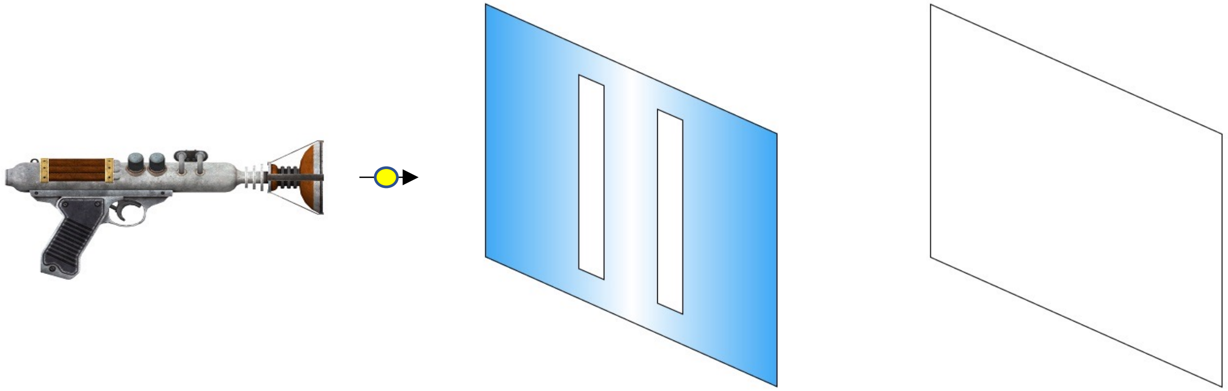
In 1905, Einstein showed in photoelectric experiment that

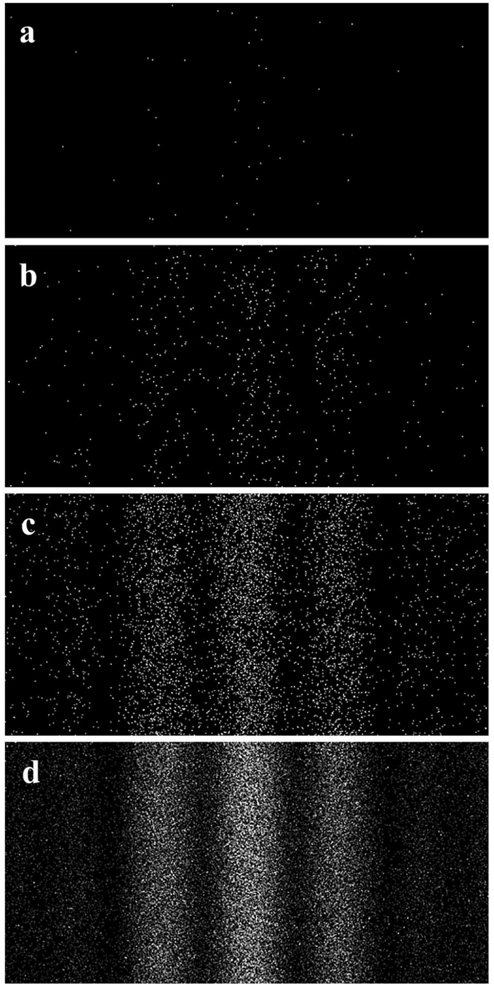
Light is particle.

What exactly is particle?

What exactly is particle?

Double-slit experiment using single electrons.





https://www.nature.com/articles/s41598-018-19380-4/figures/1

What exactly is particle?

An electron behaves like a wave!

What exactly is particle?

- In general scattering, an electron behaves like a particle.
- In double-slit experiment, an electron behaves like a wave.

So, an electron could be either particle or wave depending on what it is doing.

Wave-Particle Duality

What exactly is particle?

OK, but what kind of wave is that?

This question will be answered in the afternoon Quantum Mechanics session.

What exactly is particle?

Classical Mechanics

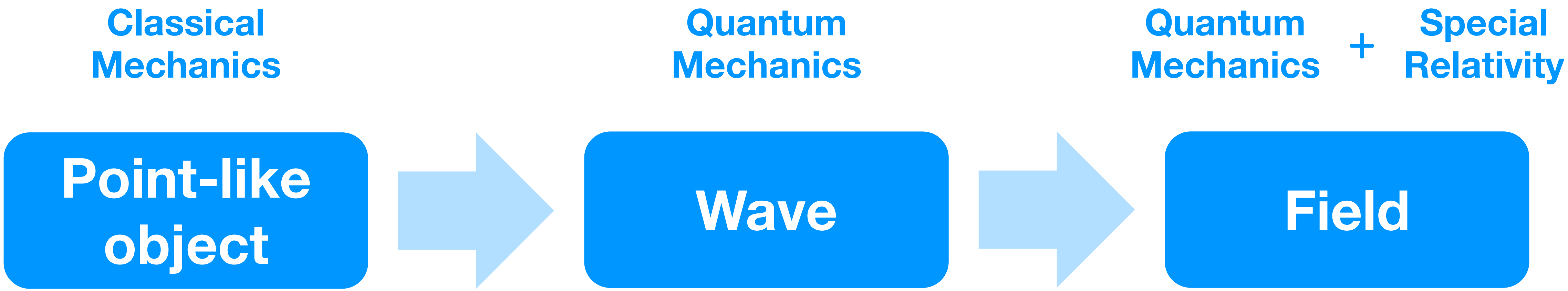
Point-like object

→

Quantum Mechanics

Wave

What exactly is particle?



Particles are quanta of their quantum fields.

How does physics study high energy particles?

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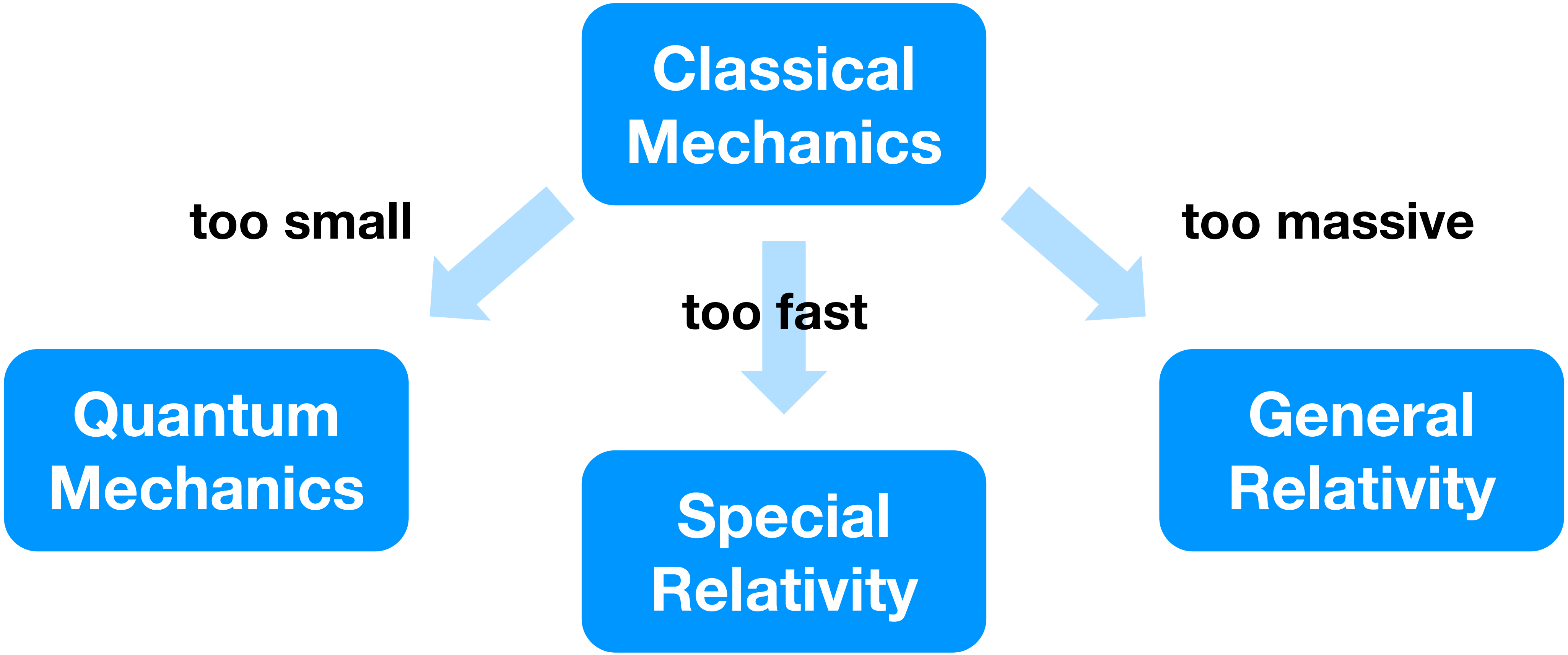
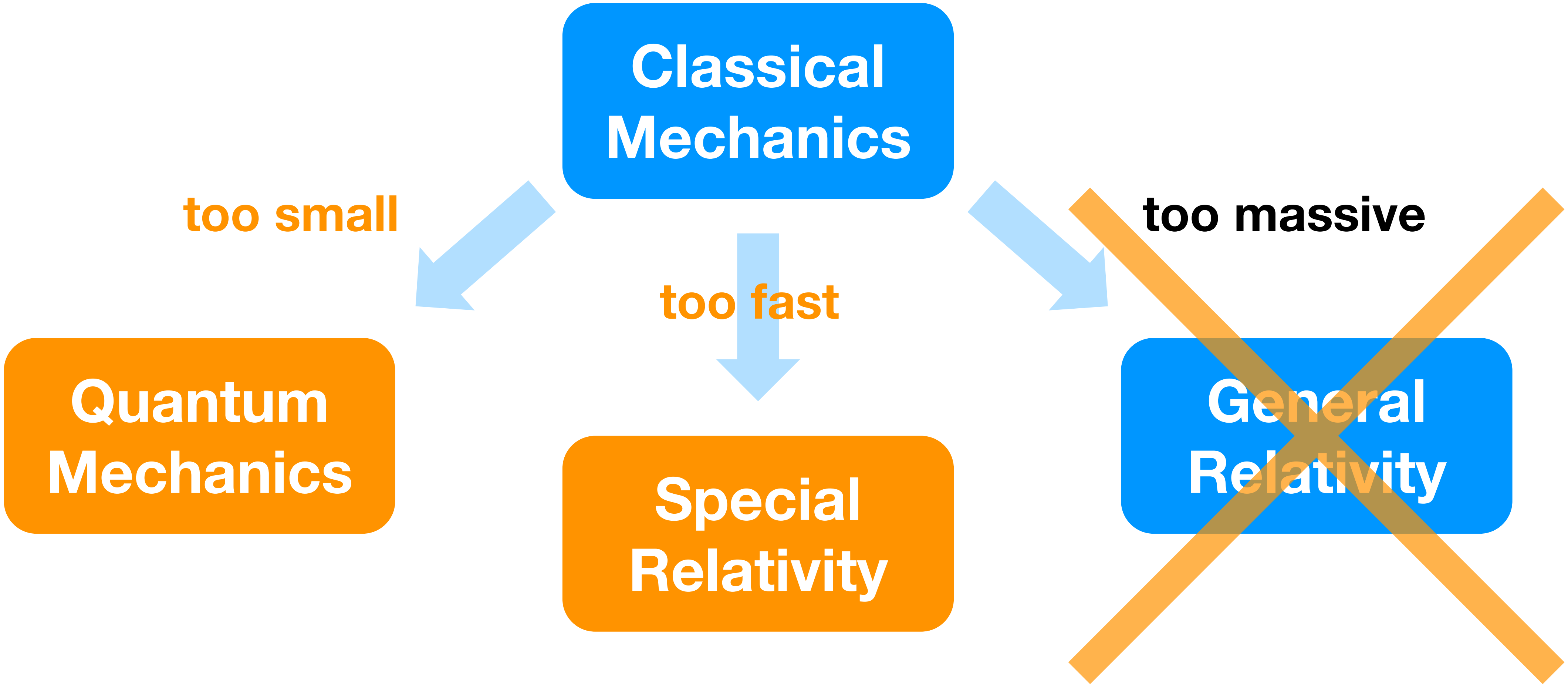


How does physics study high energy particles?



How does physics study high energy particles?

Quantum Mechanics + Special Relativity

Quantum Field Theory

Particles are quanta of their fields.

How does physics study high energy particles?

Quantum Mechanics + Special Relativity + Theory about Symmetry

Quantum Field Theory

Particles are quanta of their fields.

\+

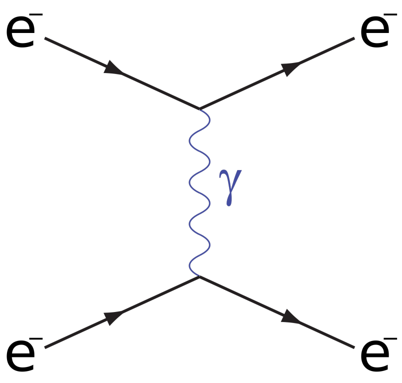
Feynman Diagram

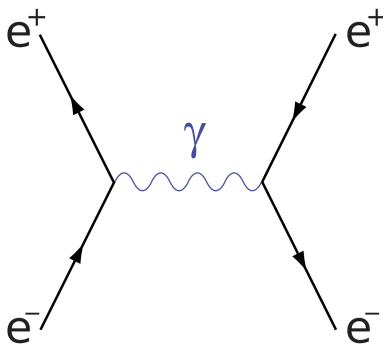
with some rules

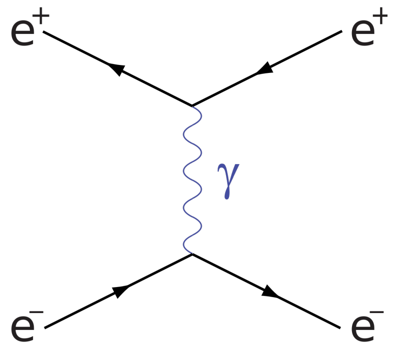
Special Relativity

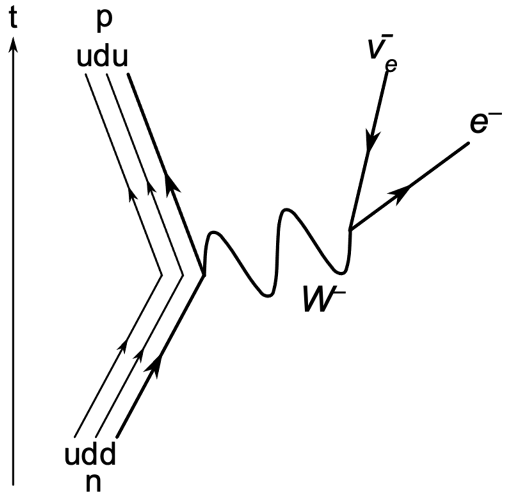
Classical Mechanics	Special Relativity (1905)
The measurements of space and time are absolute (not depended on the frame of reference).	The measurements of space and time are depended on the frame of reference. The speed of light is instead absolute.
3-dimensional space and 1-dimensional time are separated	Space and time are combined as 4-dimensional space-time.
Two inertial frames of reference transform under Galilean Transformation.	Two inertial frames of reference transform under Lorentz Transformation.
Space and time are flat.	Space-time is flat.

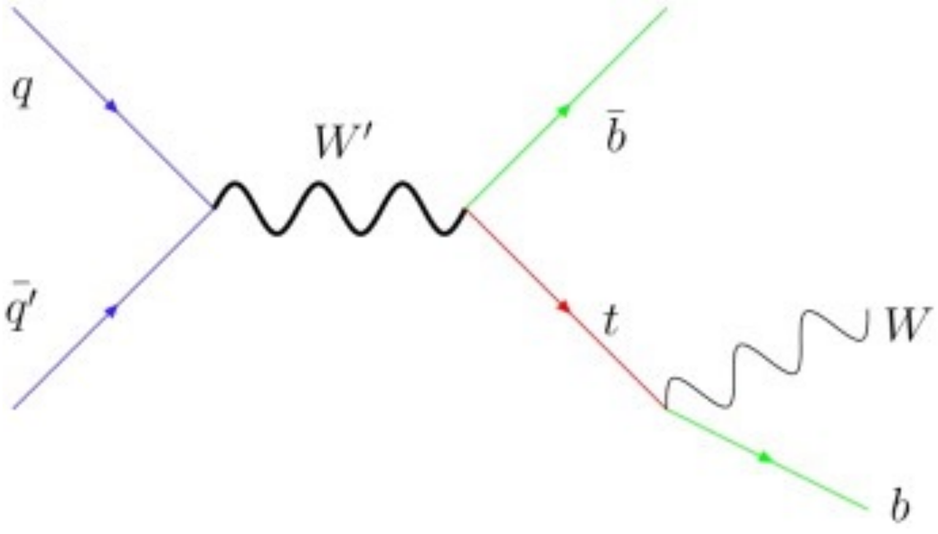
Feynman Diagram











Let’s get a bit more abstract.

Lagrangian Mechanics

Newtonian Mechanics (1687)

Force **plays the most important role in the dynamics of a moving object. With known force function, *Newton's Laws of Motion* define the equation of motion of an object.**

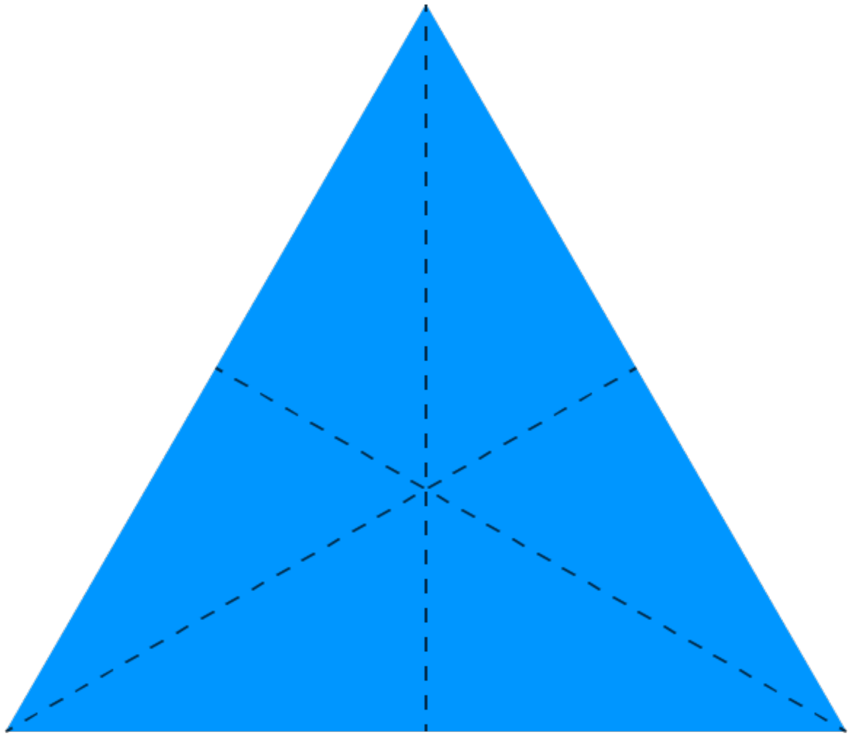
Lagrangian Mechanics (178X)

The dynamics of a moving object is represented by *Lagrangian*. With known lagrangian, *Euler-Lagrange Equation* define the equation of motion of an object.

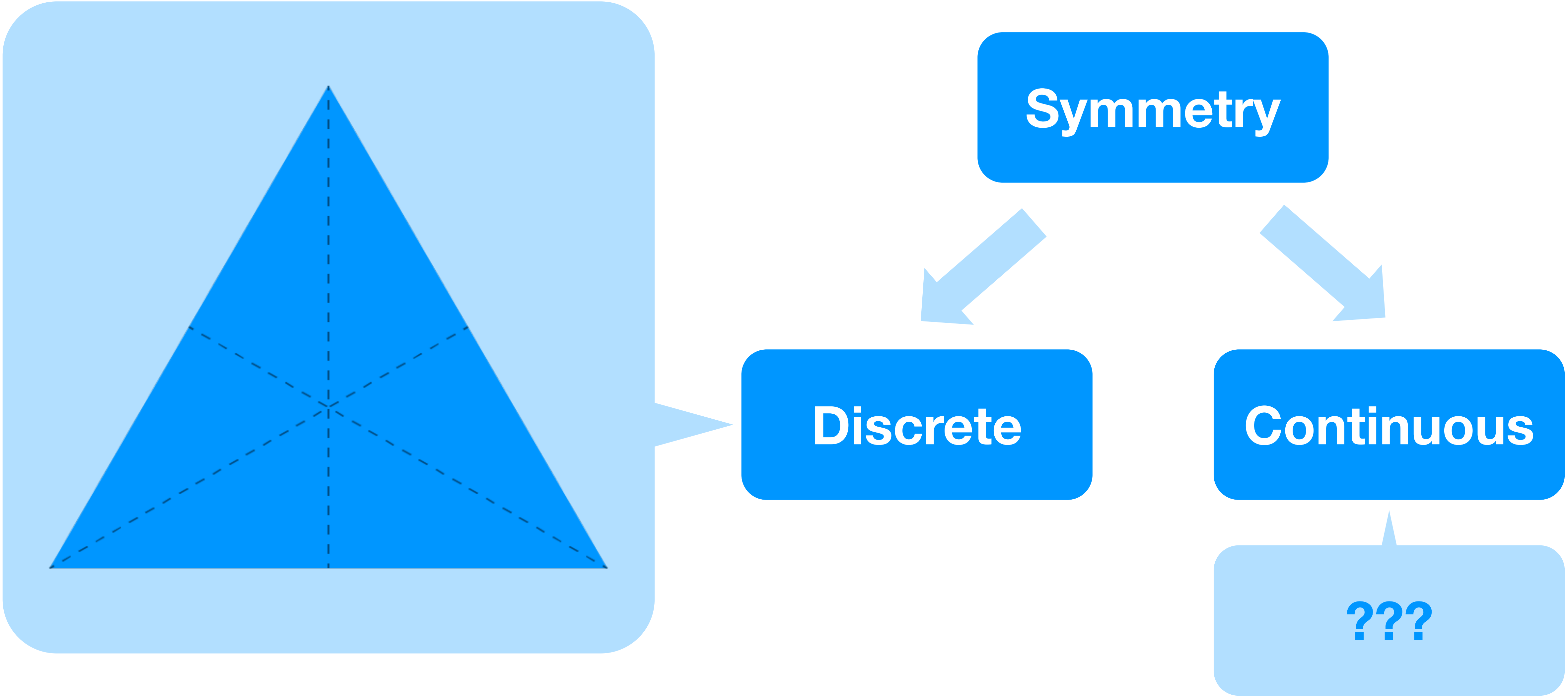
$$\frac{d^2x}{dt^2} = \frac{1}{m}\vec{F}(x,t)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) = \frac{\partial L}{\partial q}$$

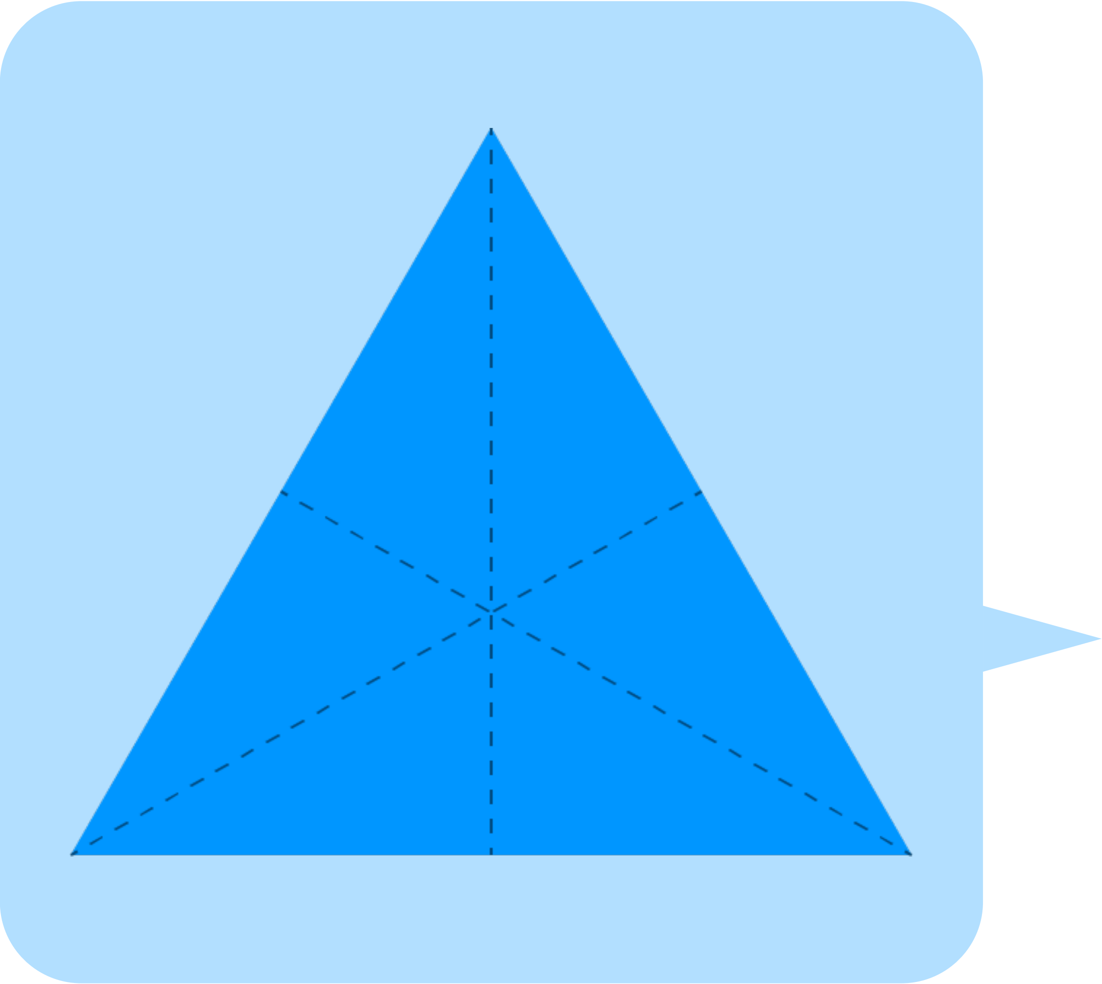
Symmetry

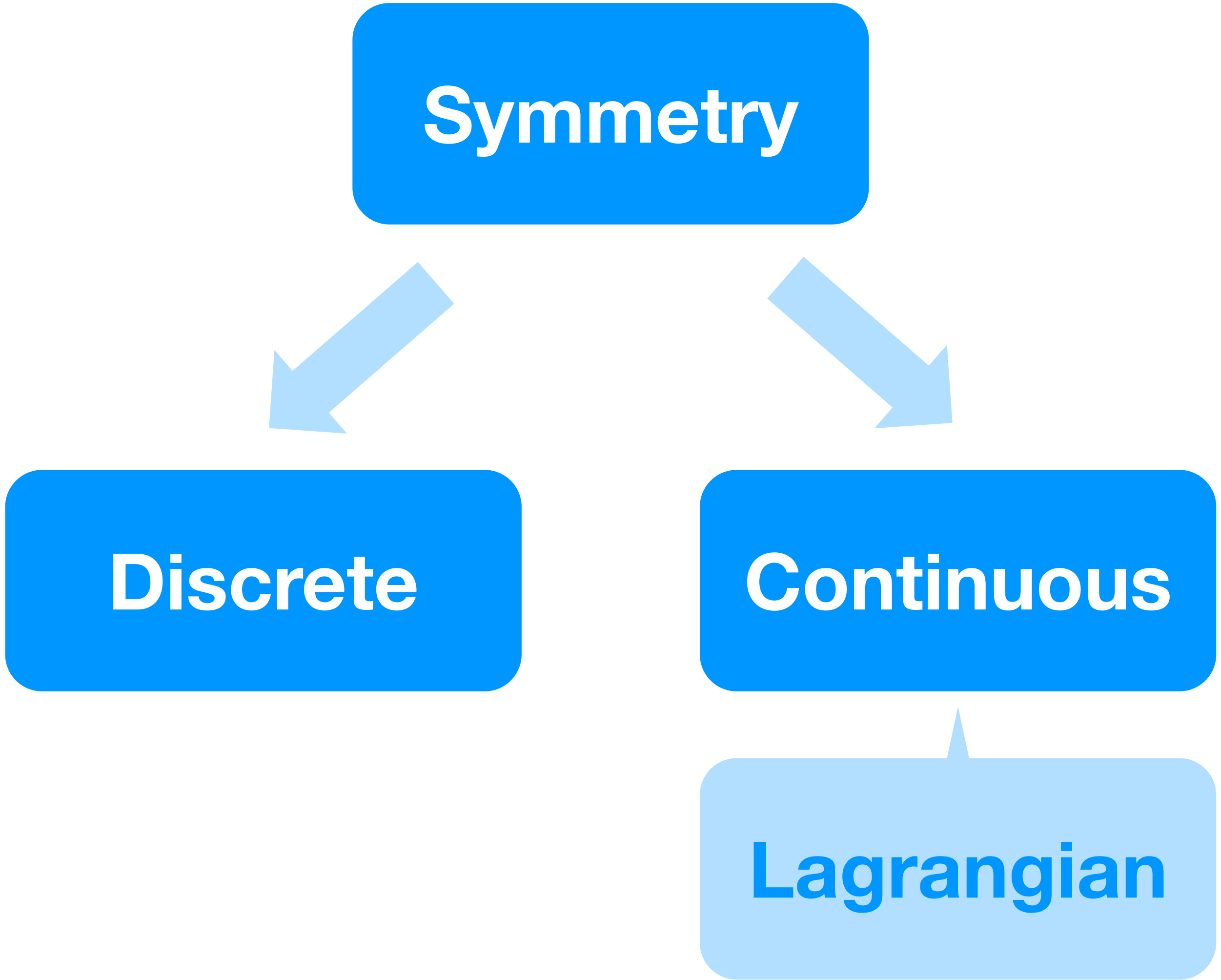


Symmetry



Symmetry





Symmetries and Conservation Laws

For every continuous symmetry, there is a corresponding conservation law.

In particle physics, we focus on the symmetry of lagrangian which is a function of fields.

Symmetries and Conservation Laws

Symmetry	Conservation
Translation	Momentum
Rotation	Angular Momentum
Time	Energy

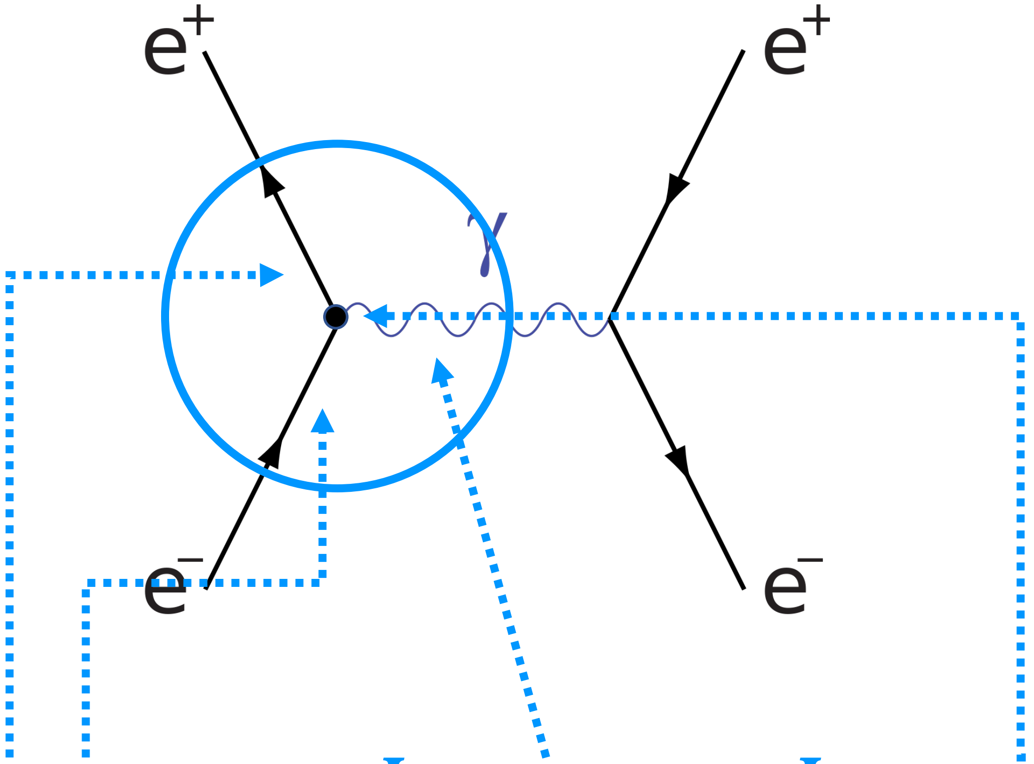
Gauge Theory

When lagrangian is required to be invariant under a particular phase transformation, it gives rise to additional terms in the lagrangian:

- **the term for the corresponding gauge boson field**
- **and the interaction term**

$$L = L_{fermion} + L_{boson} + L_{interaction}$$

Feynman Calculus



$$L = L_{fermion} + L_{boson} + L_{interaction}$$

Out of lagrangian, Feynman came up with diagrams and rules which allow us to calculate important quantity such as life time, decay rate, cross section, etc.

In Conclusion

Quantum Mechanics + Special Relativity + Theory about Symmetry + Feynman Diagram

Quantum Field Theory

Particles are quanta of their fields.

with some rules

Physicists use the beauty of the nature to study its beauty.