

This course is called "Particle Physics" but really it should be called "Physics at the fundamental frontiers with which we are currently confident". I say that because not only will we find that the notion of "particles" as we usually understand them is not part of it, but also because the subject itself has undeniable hints at physics beyond what it is currently capable of describing.

Let's start with some high-level nomenclature\*:

- Framework (Mechanics) - a framework for describing the evolution of a system
  - Theory - a framework applied to a particular context
  - Model - an effective theory that requires some inputs that are not predicted by the theory itself, but are selected to match desired behavior
- } contrast SR w/ GR

\* Note, not everyone agrees on the use of these terms, but then again this is not mathematics!

Let's start by establishing the appropriate mechanics for our purposes.

**Non-relativistic (Newtonian) Mechanics**

- valid for low speeds
- 3D space + absolute time
- Galilean relativity  $v = v' + u$   
     ↑           ↑  
   as seen in S   as seen in S'



**Relativistic Mechanics**

- valid for any speeds
- 3+1 D spacetime
- Special relativity  $v = \frac{v' + u}{1 + \frac{v'u}{c^2}}$   
     gives constancy of c

Correspondence principle: If  $v'u \ll c^2 \Rightarrow v = \frac{v' + u}{1 + \frac{v'u}{c^2}} \approx v' + u$

But do we need to work with relativity?

Well to compare w/ experiment where speeds approach  $0.9999999 < (\rightarrow \text{mph} < c)$  we do!

But more importantly, if we want a fundamental description, we want one that is right in any situation.

### Non-relativistic (Newtonian) Mechanics

- valid for large decoherent systems
- deterministic, i.e. given initial conditions and dynamics, solution is unique behavior
- $H$  or  $L \Rightarrow$  e.o.m. w/ b.c.s  $\Rightarrow x(t)$

### Non-relativistic Quantum Mechanics

- valid for all systems
- probabilistic, i.e. given initial conditions and dynamics, solution is probability distribution for possible behaviors
- $i\hbar \frac{\partial \psi}{\partial t} = H\psi$  w/ b.c.s  $\Rightarrow \psi(x,t)$   
 $|\psi|^2 \sim \text{prob.}$

Correspondence principle: harder to pore because the "questions" change, but generally when  $S = \int L dt \gg \hbar$ , we get classical behavior dominating.

Do we need QM? Well we are studying a small number of hella small things, so yeah!  
But again, to be fundamental the description should always work.

Of course we are then led to ask, "What about small things at high speeds?"

The answer naively would be Relativistic Quantum Mechanics, but this is slightly problematic.

QM relies on  $\int |\psi|^2 dx = 1$  wavefunction normalization to establish probabilities  
The particle has to be somewhere!

But...

Relativity allows particles to be created and destroyed!

To get around this we could introduce a Fock space of particle states to allow particle creation/annihilation in QM. This does work to some degree, but it is cumbersome and incomplete!

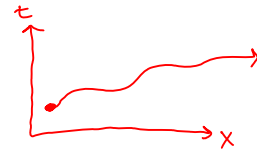
So what do we use?

# Quantum Field Theory

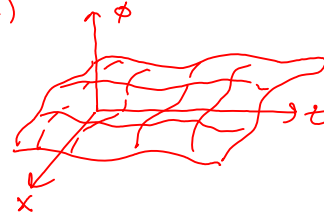
QFT achieves many things:

- Gives natural origin of identical particles
- Gives natural weights to creation/annihilation processes
- Yields spin-statistics theorem
- Allows non-perturbative phenomena

Particle:  $x(t)$



Field:  $\phi(x,t)$



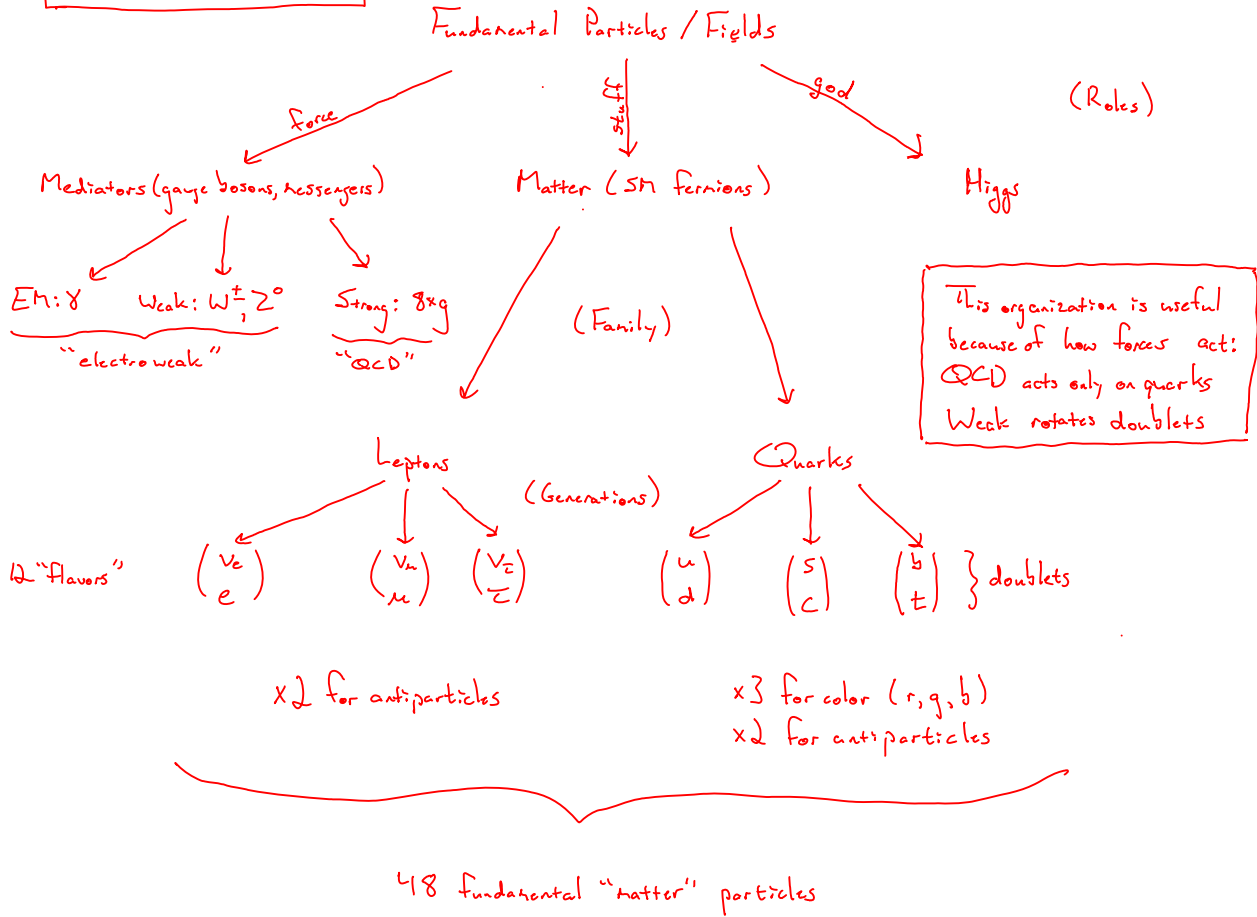
Correspondence Principle

⇓ localized fluctuations

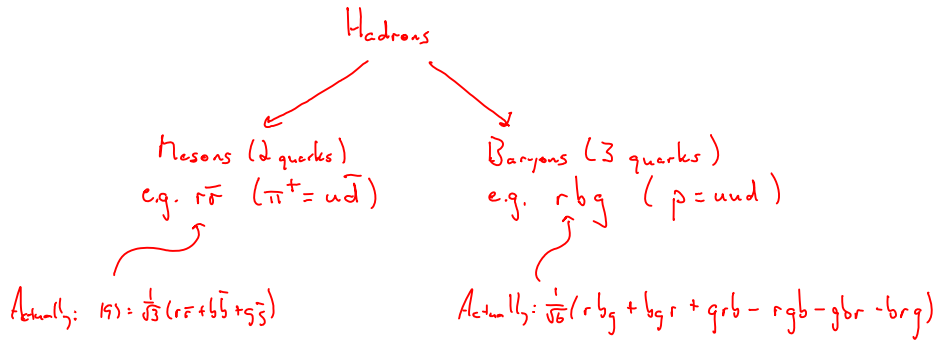


look like particles!

**Overview of the SM**



We typically see lightest leptons ( $\nu_e, e$ ) and quark bound states (color neutral).



This model has 19 parameters which can only be deduced from experiment.

## Outline of course:

- Formalism
- Develop systematic approach to transformations and symmetries
  - Review special relativity
  - Review Lagrangian mechanics
  - Develop Lagrangian mechanics of scalar, spinor and vector fields
  - Introduce interactions through local gauge invariance
  - Discuss SSB and Higgs
  - Special topics
- Calculations
- Lay out an approach to calculations
  - Review perturbation theory
  - Develop and apply Feynman calculus
  - Review classic calculations
  - Renormalization
  - Special topics