Today’s lecture:
- Overview of the Science for this semester
- Overview of course structure etc

But first: why is this course in English?
- Graduate courses and our English Masters
- Particle physics is done in English
- Scientists need to be English-proficient. Sooner is better!
2: Physics and Reductionism

Physics is reductionist. We always want to explain the *large and complicated* based on the *small and simple* constituents

- Condensed matter is made of molecules
- Molecules are made of atoms
- Atoms are made of $e^-$, $\gamma$, nuclei (eg, $^{12}C$)
  - $e^-$ and $\gamma$ appear to be **fundamental**
- Nuclei are made of $p^+$, $n$
- $p^+$, $n$ are made of ... **quarks and gluons**
- Quarks and gluons appear to be fundamental

If we understand the quarks and gluons, we can explain $p^+, n$

Understand those, $e^-$, $\gamma$, and we understand atoms (QED)

Atoms get to molecules, molecules explain condensed matter

It’s not really that simple: **More is different** Philip Anderson, Science Vol 177 Issue 4047 pp 393-396 (1972)
Relativity: there is a *fundamental relation* between length and time

\[ x \sim ct \]

Quantum: there is a *fundamental relation* between length and momentum:

\[ p \sim \frac{\hbar}{x} \quad \text{and therefore} \quad E \sim \frac{\hbar c}{x} \sim \frac{\hbar}{t} \]

To study the *fundamental* (small-scale) we need to use *high energies and momenta*. The higher the energy we study, the shorter the lengths and the more fundamental the interactions we can elucidate.
There is a *symmetry* between distance and time. It’s *crazy* to use different units for each. Time should be measured in meters (or distance in light-seconds).

There’s a *deep relation* (QM) between momentum and wave-number. We can either use inverse-length to measure momentum, or inverse-momentum (or inverse-energy) to measure length.

Particle physics conventions: fundamental unit is energy. Joules are awkwardly large. MeV or GeV are better

\[
1 \text{ eV} \approx 1.6 \times 10^{-19} \text{ J} = 1.6 \times 10^{-19} \frac{\text{kg m}^2}{\text{s}^2} \quad 1 \text{ GeV} \approx 1.6 \times 10^{-10} \text{ J}
\]
5: Particle physics units

I measure energies in GeV.
I measure momenta in GeV. (for you, GeV/c)
I measure lengths in 1/GeV (for you, ℏc/GeV)

Alternately: lengths are in Fermi 1 fm = 10^{−15} m
Energies are in 1/fm (really ℏc/fm)
Momenta are in 1/fm (really ℏ/fm)

The relation between these is:

\[ ℏc = 0.197 \text{ GeV fm} \]

Particle physicists “use units where ℏ = 1 = c” or suppress writing ℏ, c factors
Symmetries are super-important. They tell us what particles are stable and which can decay into something else.

Symmetries you already know (Classical Mechanics)

▶ Translation invariance: momentum is conserved!
▶ Time-translation invariance: energy is conserved!
  Taken together: light particles are most often stable, heavy particles typically decay
▶ Rotation invariance: angular momentum is conserved!
  QM: total angular momentum must be a half-integer (times $\hbar$)
7: Why Bosons carry forces and Fermions form matter
There is a *deep result* about light “fundamental” particles: not all spins occur:

- Spin-0 is fine.
- Spin-$\frac{1}{2}$ is fine
- Spin-1 is fine **but** only as a gauge field, that is, coupling in a way similar to the photon of electromagnetism
- Spin-2: there can only be one such particle and it must be the graviton of general-relativistic gravity
- Spin-$\frac{3}{2}$: there can only be one such particle, only in supersymmetric theories, and it must be the gravitino
- Higher spins are forbidden

But for *composite* particles built out of lighter things, any spin is OK (think of all stable atoms and ions).
9: Particles of the Standard Model

- **Spin 0**: Higgs boson $H$ induces masses in other particles

- **Spin 1**: Force carriers
  - Photon $\gamma$: Electromagnetism
  - Weak bosons $W^\pm, Z$: Weak interactions
  - Gluons $g$: Strong (color) force

- **Spin 1/2**: Matter fields
  - $e^-, \mu^-, \tau^-$: EM (charge $-1$) and Weak only
  - $\nu_e, \nu_\mu, \nu_\tau$: weak only (charge 0)
  - $u^c, d^c$ quarks: strong, EM (charge $2/3$), and weak interactions
  - $s^c, b^c$ quarks: strong, EM (charge $-1/3$), and weak interactions

Note: every particle has an antiparticle. $H, \gamma, Z, g$ are their own antiparticles.
The others have an antiparticle of opposite charge (and color)

Matter particles come in triplicate: light, medium, heavy (“flavors”)
What is with these charge $\frac{2}{3}$, $-\frac{1}{3}$ colored quarks? Don’t all particles have integer electric charge?

The strong force is strong! It holds quarks together in hadrons. Try to pull a quark out: force required is more than the force it takes to hold up an elephant!

The allowed “colorless” combinations are $q\bar{q}$, $qqq$, or anything else with a net multiple-of-3 number of quarks.

Obviously we will talk more about this!
That’s a super-fast summary. Starting next week, we do details:

3. Relativistic kinematics, eg, Relativity again
4. Symmetries and conservation laws
6. Feynman diagrams
7. Quantum Electrodynamics QED
8. Quantum Chromodynamics QCD: the strong force
9. Weak interactions
10. More about gauge theories

Numeration is the same as the chapters of Griffiths
That means you are *already behind* in your reading – please read chapters 1 and 2, which are overview and summary material
Meanwhile, what about our course?

- Readings, ideally before each lecture
- Lectures, Tuesday + Friday
- Homeworks, posted on the course page
  - Released every Friday
  - Due the next Friday, electronically to the assistant, by 13:30
- Homeworks + solutions are password protected
  Password sent separately by email
- Weekly homework help sessions (see webpage)

I will follow the book closely.

**It is essential** that you get the book and do the readings.

**It is essential** that you work on the homework sets.

Everything else is optional, but hopefully helpful.
13: Course grade

The course grade will be based mostly on an exam.

▶ Standard 2 hour in-person exam
▶ 2 pages front-and-back of hand-written notes
▶ No electronic assistance

The homeworks contribute to your grade!

▶ Everyone has a bad week – I will throw out your lowest % graded homework or ignore the one assignment you did not turn in
▶ If you get over 60% on the homeworks, it adds 1/3 to your grade
▶ If everyone prefers it, we can do away with the exam and base the grade solely on the homeworks. In this case there will be one extra “summary” homework.