Teilchenphysik:

Introduction

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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^-, γ, nuclei (eg, ^{12}C)
  e^- and γ 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^-, γ, 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)

3: Relativity, Quantum Mechanics, and Scales

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.

4: Particle physics and Units

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

$$1\,\mathrm{eV} \simeq 1.6 \times 10^{-19}\,\mathrm{J} = 1.6 \times 10^{-19}\,\frac{\mathrm{kg\,m^2}}{\mathrm{s^2}} \qquad 1\,\mathrm{GeV} \simeq 1.6 \times 10^{-10}\,\mathrm{J}$$

5: Particle physics units

I measure energies in GeV.
I measure momenta in GeV. (for you, GeV/c)
I measure lengths in $1/\text{GeV}$ (for you, $\hbar c/\text{GeV}$)

Alternately: lengths are in Fermi 1 fm = 10^{-15} m
Energies are in $1/\text{fm}$ (really $\hbar c/\text{fm}$)
Momenta are in $1/\text{fm}$ (really $\hbar/\text{fm}$)

The relation between these is:

$$\hbar c = 0.197\,\text{GeV fm}$$

Particle physicists "use units where $\hbar = 1 = c$" or suppress writing $\hbar$, c factors

6: Symmetries and Conservation Laws

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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

8: What spins to expect as fundamental particles

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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

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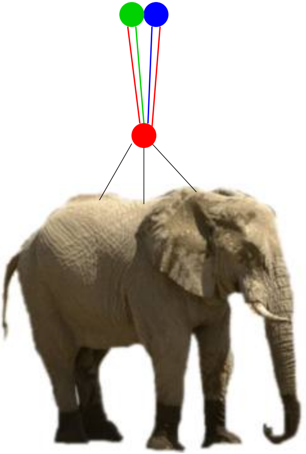
- **Spin 0: Higgs boson** H induces masses in other particles
- **Spin 1: Force carriers**
  - **Photon** γ: Electromagnetism
  - **Weak bosons** $W^{\pm}, Z$: Weak interactions
  - **Gluons** g: Strong (color) force
- **Spin 1/2: Matter fields**
  - e^{-}, μ^{-}, τ^{-}: EM (charge -1) and Weak only
  - ν_e, ν_μ, ν_τ: weak only (charge 0)
  - *uct* quarks: strong, EM (charge $2/3$), and weak interactions
  - *dsb* quarks: strong, EM (charge $-1/3$), and weak interactions

Note: every particle has an *antiparticle*.
H, γ, 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”)

10: The strong interactions are strong!



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!

11: Topics for the semester

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

12: Course organization

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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 assistence

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.