Lesson (1)

Introduction to EFT

(1) We will talk about EFT and some of its applications to particle physics.

Why did I choose this topic?

a) the idea of EFT is very simple, very general, and very powerful to explore almost all domains of physics. Once you learn the ideas, you can apply them where you need them.

b) it is a QFT, so results can be calculated systematically, even when approximate.
You know what you leave out.
It's predictive. Can be used when comparison with experiment is needed.

c) there are more nice aspects of it that will become clear as we go.

d) I assume that you remember what we have seen together in QFT A+B.
In particular: the idea of renormalization and its consequences (e.g. renormal. group, running of couplings, scaling, etc.)

(2) EFT are about describing the physics of a system at a given scale without knowing it at a different scale! In particular: describing the physics at

low energy (long distance) ⟷ high energy (short distance)

without knowing the physics at

Why is this approach valid?

Because you retain the IR information, but you are not influenced by the UV behavior if your EFT has a realm of validity that keeps you away from the UV.

↳ as we will see, the $\mathcal{L}_{EFT}$ will be organized in inverse powers of the Λ cutoff.

↳ we will see this systematically.

there are 2 aspects to this: → top-down approach

(2.a) if you know the physics at short-distance/h.e., you can ignore it in the details of your calculation, provided you keep a memory of it in the parameters of your low energy physics.

Example: flavor physics / meson physics
K, B - physics.

↳ EW + strong interactions

$\mathcal{L}_{SM}$

t, W, Z, H ———————— EW scale ~ 200 GeV

$\cancel{t}, \cancel{W}, \cancel{Z}, \cancel{H}$ $\mathcal{L}_{Eff}$ → contains new pointlike interactions.

b ———————— B-mesons ~ 5-10 GeV

$\cancel{b}$ ———————— D-mesons $\sim < 5$ GeV

$\cancel{c}$ ———————— K. mesons $\sim <$ GeV

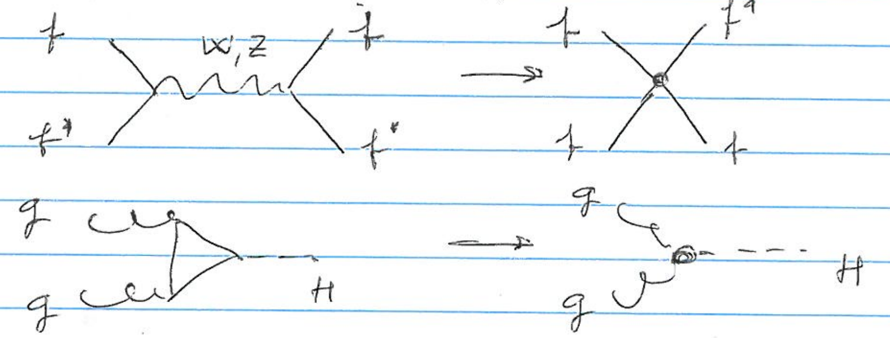
$\cancel{s}$ etc. $\simeq \Lambda_{QCD}$

need an exp. parameter $\delta = \frac{m_i}{\Lambda} = \frac{p}{\Lambda}$

→ at each threshold you only keep the d.o.f. that are physical, and you assure continuity by matching to the complete theory above threshold.

↳ we will learn how this is done properly

Let's get back to the transition $\mathcal{L}_{SM} \to \mathcal{L}_{eff}$
things like these happen:



→ seemingly new interactions.
Not allowed in the full theory, but we do not worry because the EFT is a "low energy approx." of it.

↓

$$\mathcal{L}_{eff} = \mathcal{L}_{SM}\Big|_{<\Lambda} + \sum_i c_i O_i$$

O_i ⟶ local operators

c_i ↓ coeffs. (Wilson coeffs.)

think of these as new parameters, couplings in your lagrangian (be ready to study their evolution!)

bottom-up approach

(2.b) if you do not know the physics at h.e/short distance

↓

Use the knowledge of (2.a), and the fact that an EFT is a full-fledged QFT, to build $\mathcal{L}_{eff}$!

Here we need to be more specific about our QFT constraints and bring back some concepts.
We can write our starting $\mathcal{L}$ as:

$$\mathcal{L} = \mathcal{L}_{d\leq 4} + \mathcal{L}_5 + \mathcal{L}_6 + \dots$$

$S = \int d^4x\, \mathcal{L}$ → adimensional in units of $\hbar = 1$

↳ $[\mathcal{L}] = 4$

each $\mathcal{L}_d$:

$$\mathcal{L}_d = \sum_i \frac{c_i^{(d)} O_i^{(d)}}{\Lambda^{d-4}} = \sum_i c_i^{(d)} O_i^{(d)}$$ if we leave in 4-dim (or replace it with D)

$\mathcal{L}_{d\le 4} \rightarrow [c_i] \ge 0$

$\mathcal{L}_{d>4} \rightarrow [c_i] < 0 \rightarrow \mathcal{L}_{5,6,\ldots} = \sum_i c_i^{(d)} O_i^{(d)}$

$$[O_i] = p^{d-4} \leftarrow \frac{c_i}{\Lambda^2}$$

↓

h.o. corrections introduce p-dependent terms/behavior that spoil the predictivity of the theory.

↓

hence $\mathcal{L}_{d\le 4}$ is the "good" or "renormalizable" part of the $\mathcal{L}$.

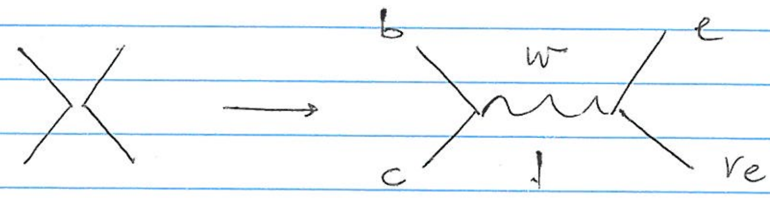
Expand:

→ new approach: EFT validity is unspoiled, hence good tool to explore new physics.

→ You can think EFT as an expansion in $\left(\frac{p}{\Lambda}\right)^{d-4}$.

↳ EFT range of validity is right here

Example: Fermi interaction:



$$\frac{1}{p^2-M_W^2} = -\frac{1}{M_W^2}\left(1+\frac{p^2}{M_W^2}+\frac{p^4}{M_W^4}+\cdots\right)$$