

The mass dimension of ϕ is telling you about the size of its fluctuations.

For positive mass dimension the fluctuations in ϕ get smaller & smaller @ larger distances, Conversely they get larger & larger @ smaller distances.

$$\int d^4x \lambda \Phi^4(x)$$

↳ units of λ - dimensionless

$$+ m \Phi^3(x)$$

↳ mass dimension 1

$$\frac{1}{M^2} \Phi^6(x) + \frac{1}{M^4} \Phi^8(x) + \frac{1}{M^2} \Phi^2 2\phi 2\phi + \dots$$

tons of things you could write down, but the vast majority of interactions have a straight that is an inverse power of mass.

Only a few interactions are dimensionless, ~~or~~ or have positive mass dimension.

dimensionless - marginal

positive mass dim - relevant

negative mass dim - IRREL

Gravity is example of Irrel operator, No invariant sense of work staying or work

- At low energy scales so weak that unimportant

- At high energy scales so important that we need to change theory.

Any ^{ense} invariant theory comes equipped w/ scale at which it breaks down.

In any given theory, if you want to describe physics around some fixed energy scale, All you need to know are

-) What are the particles around. (fields associated w/ them)
-) What are the possible marginal or relevant interactions between them? Write them all down

Only a few parameters, whatever is going on @ these energy scales can be accurately described by those few parameters and nothing else.

If you want to predict things very accurately then maybe you need to include the next terms.

Relevant terms only important at very low energies.

Always like to think of approximation, where the particles are moving fast compared to their masses, energies are high

In that approximation the only things that matter are the marginal interactions.

In all cases in physics there is some physical scale M in which your description of the physics is wrong. (often called UV cut-off)

eg: Planck scale the whole picture is wrong.

But if we are at energies much lower than M_p we do it even

What's happening at the higher scales is encoded in the higher dim operators.

The way to organize your thinking is scale-by-scale.

All the thinking goes into determining the interactions.

Guaranteed to be finite # of parameters at any given scale to describe the physics accurately.

Any theory that we write down is an effective theory that is only accurate to order powers of $\frac{E}{M_{\text{New}}}$

(There is something always to $\frac{E}{M_p}$ that we don't know even if we understand 1 TeV, 10 - 100 ... at)

Tower of effective field theories each accompanied by its own cut off.

this is the bottomline to Wilson's way of thinking.

Massive restriction to the kinds of interactions that we can have and that are relevant.

↳ incredibly different from non-relativistic QM!

- Any crappy potential that I want ($\frac{1}{r} \dots \frac{1}{r^{2.3}}$ random linear combinations etc)

- framework itself is incredibly unconstrained

The second we put in SR + QM,

- drastic kinematic things (Anti-particles / Spin stats)

- the number of interactions that we are talking about are numbers we can count on our hands.

In SM ~ 19 marginal interactions

↳ Not 1, but not continuous ∞ , which is what you get in a NR picture of the world.

Now for a little bit more ...

think about limit in which can neglect the mass of all particles, imagining high energy processes relative to mass of particles.

(Not Explained, but not so important)

All this comes out of same logic but for fermions.

$$\int d^4x \frac{1}{2} (2\phi)^2$$

$$+ \bar{\psi} \psi$$

free theory of scalars

free theory of fermions

$$\text{mass dim(Bosons)} = 1$$

$$\text{mass dim(Fermions)} = \frac{3}{2}$$

Can now write down possible interactions in 4-dim.

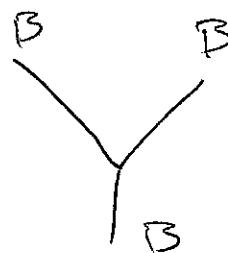
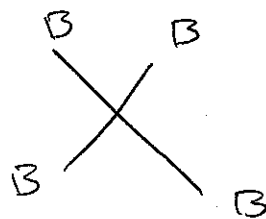
$$\phi^4$$

$$\phi^2 \psi \bar{\psi}$$

$$\psi \bar{\psi} \psi \bar{\psi}$$

this is for the marginal operators.

Basic interactions in nature



At sufficiently low energies compared to M_{Pl} , SR + QM say we need a theory of Fermions & Bosons, and these are the only interactions that are important

Dimensional Counting tells us there can only be a few types of interactions,

Now last bit of logic for why the world is such a damn constrained place ...

Furthermore, spins of the particles are bounded.

- Can't have marginal interactions of particles w/ spin bigger than one. Marginal interactions only allow spin 0, $\frac{1}{2}$, 1.
- If want them to have any interesting long distance manifestations, at all, bounded by Spin 2. (Good reason we haven't seen spin 17 massless particles)
- @ Spin 1 rules that we talked about are still not enough to guarantee Lorentz Invariance. (See this in a min)
The kind of theory you need is nailed, has to be Yang-Mills.
- For Spin 2, must be G.R.

Can have irrelevant operators that correct these, but the leading interactions are Y.M. & G.R. no choice.

Talk about why massless spin-2 particles already cause so much trouble.

Reason has to do w/ Basic fact that massless particles only have helicity

$$A_\mu(x) = \int \frac{d^3p}{(2\pi)^3} \left(e^{ipx} a_p + \sum_n \epsilon_n^\mu(p) e^{ipx} a_{p-n} + \text{h.c.} \right)$$

↳ Polarization vector

Now we encounter now related things.