How to measure Virtual particles?

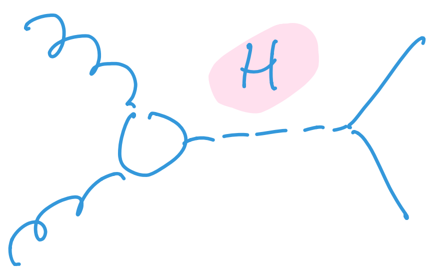
Intrinsically Quantum Mechanical question.

Quantum Mechanical Particle:

$$\psi(\vec{x}, t) = \psi(\vec{x}) \times e^{\frac{iEt}{\hbar}}$$

This is for a free particle

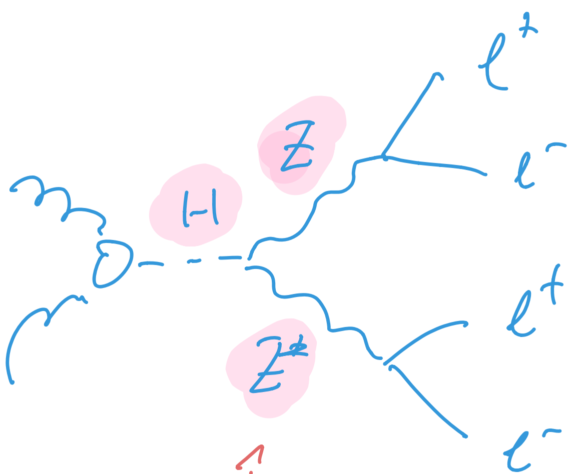
How about particles appearing in interactions?



particles in the final state

REAL PARTICLES

or



Particles that are intermediate in the interaction

CAN BE CALLED VIRTUAL

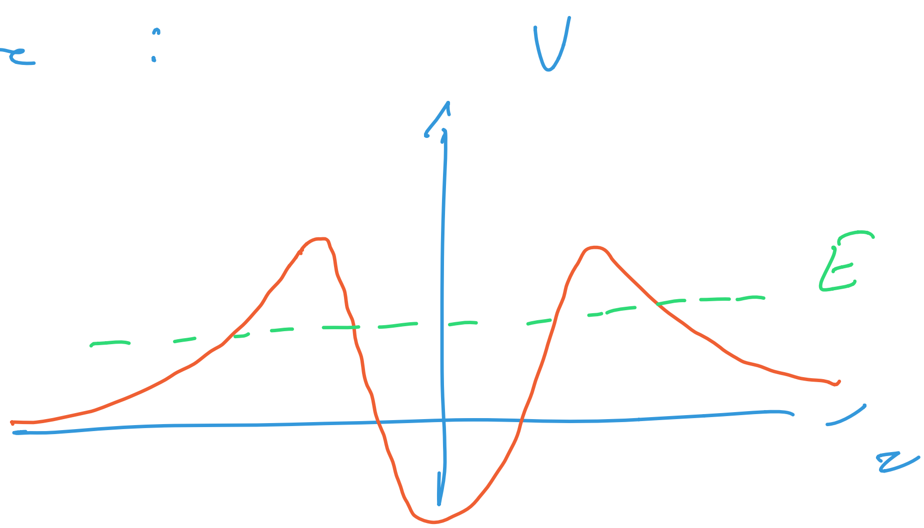
Taking a closer look at virtual particles, i.e. particles that appear as intermediates can be viewed as solutions of a damped oscillator, which can also produce resonances when excited with the right energy.

As a damped oscillator

$$E \to E - i\frac{\Gamma}{2}$$

Just add a complex term to the energy –

How this can be achieved in QM is to consider a scattering with a metastable state:



(for details see scattering theory) ~

Once $E - i\frac{\Gamma}{2}$

Then the probability to find the particle will be:

$$|\psi(\vec{x},t)|^2 = |\psi(\vec{x})|^2 e^{-\frac{\Gamma t}{\hbar}}$$

Now if we compare this to a statistical

decay law when the probability for a decay is constant:

$$N(t) = N_0 \, e^{-\frac{t}{\tau}}$$

↑ mean lifetime

Then $\frac{\Gamma}{\hbar} = \frac{1}{\tau}$

i.e. $$\boxed{\Gamma \cdot \tau = \hbar}$$

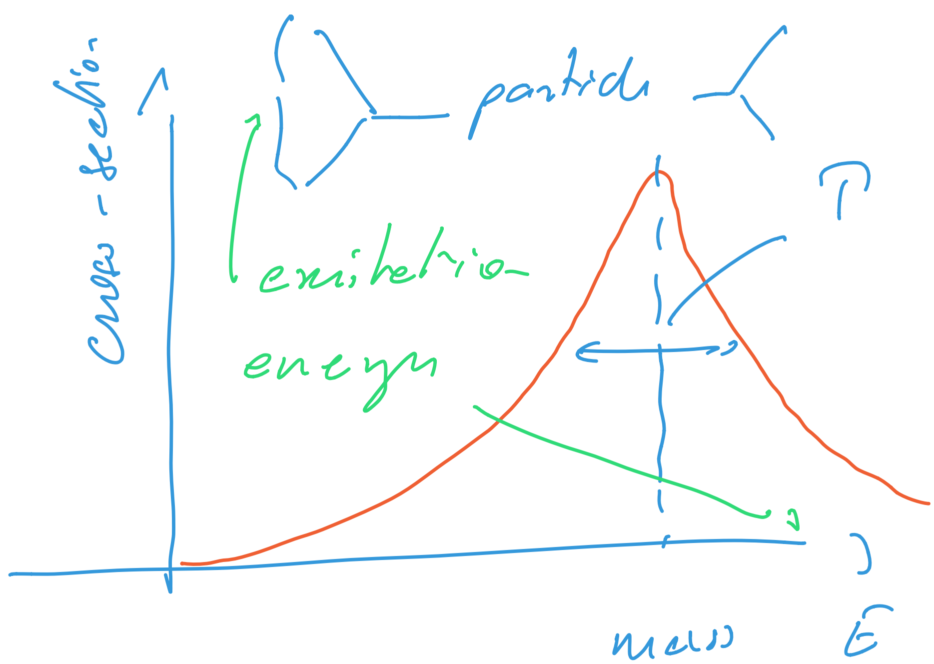
Γ → ΔE variations in energy

τ → Δt variations in time.

Γ → is the total width

τ → Particle lifetime

Γ corresponds to the width of a resonance



Exchange of virtual particles far from their mass has a cost on the rate but is very possible.

That is what happens in the case when the Higgs boson decays rapidly $(1.6 \cdot 10^{-22}\,s)$

In which case we study the decay products and infer the properties –

or when the Z^* is off-mass shell –

In both cases the particle only appears as a VIRTUAL PARTICLE

There is a more shadowy domain where the decay width is extremely small, and therefore the decay lifetime is very long e.g. muons, or pions (many more) -

These particles can be interpreted as a real particles decaying -

Δ word about energy conservation - Indeed in the case of a ΔE there is no energy conservation this is the basis of the Heisenberg Principle - (more next page)

However for the modification of the wavefunction this is done in QM scattering theory just with the potential defined above!

The concept is splendid as it allows to interpret forces not as resulting from an "ACTION AT A DISTANCE" but by the exchange of a particle!

This overall <u>does not</u> violate energy conservation, but it is rather <u>borrowed</u> for a short interval —