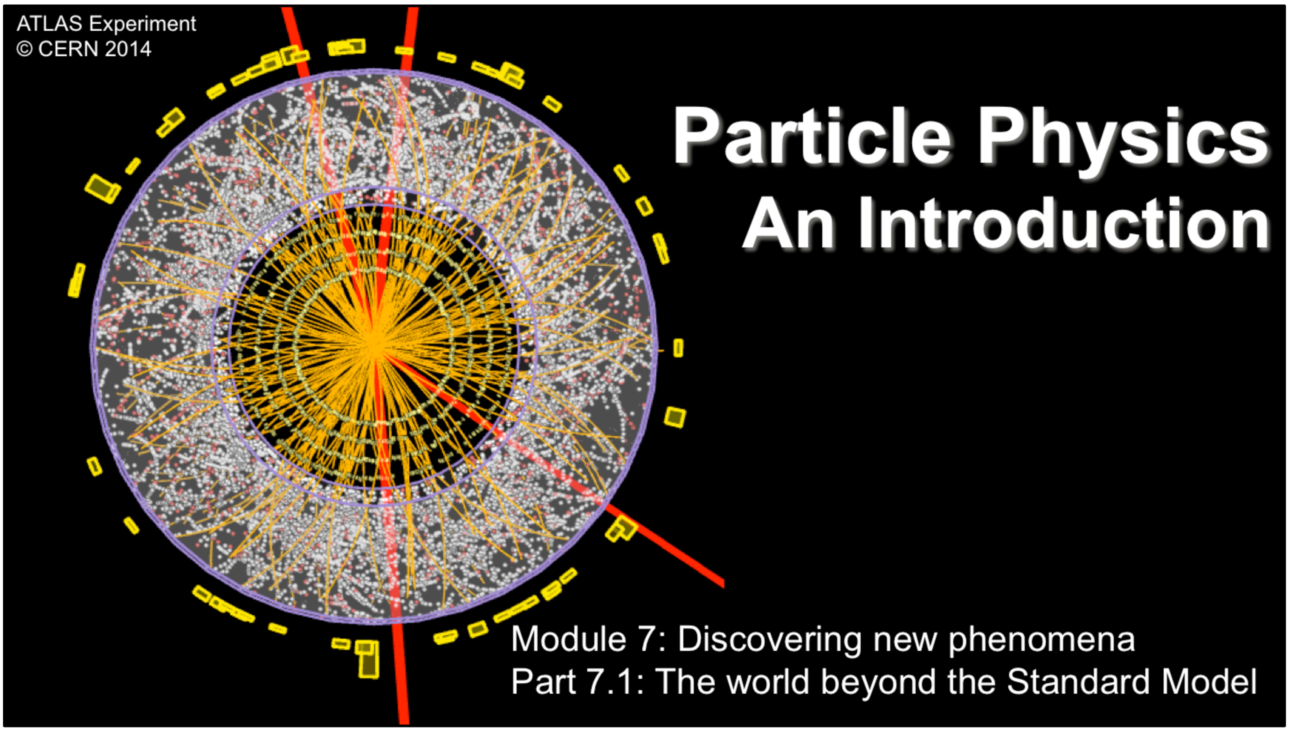
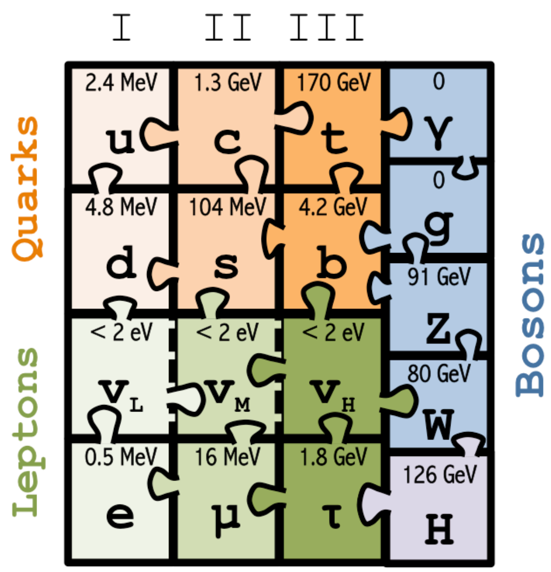


In this 7th module we discuss searches for new phenomena, beyond the known ones described by the standard model, and covered in the previous modules. We will remind you why we need new physics, we will explain how we render hadron collider data usable for searches and we will discuss examples, split in two categories based on the general characteristic of how new phenomena would manifest themselves.

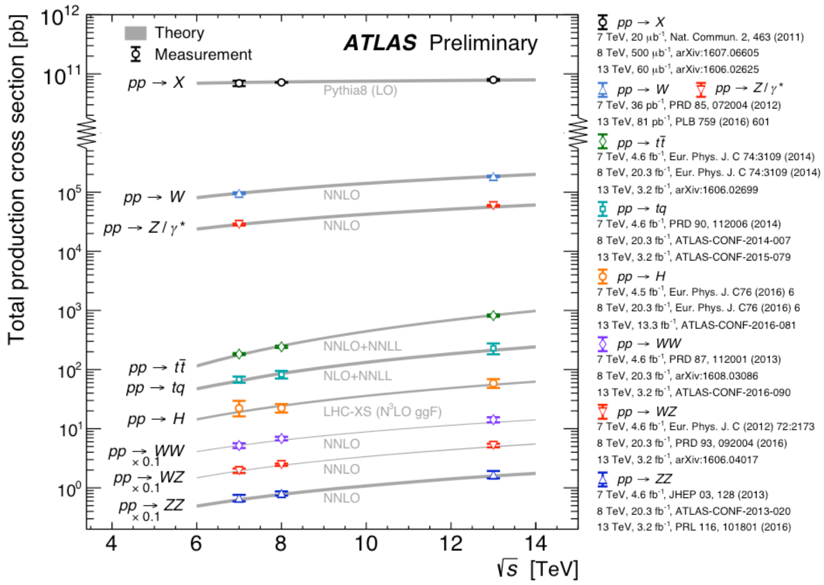
In this video we will describe the theoretical limitations of the Standard Model and talk about new theories that have been proposed to overcome them.

After watching this video you will know:

- Which are the open questions the Standard Model leaves unanswered;
- How new theories are attempting to answer them, using a particular theory as an example; and
- Where we stand in our searches using the hadron colliders.



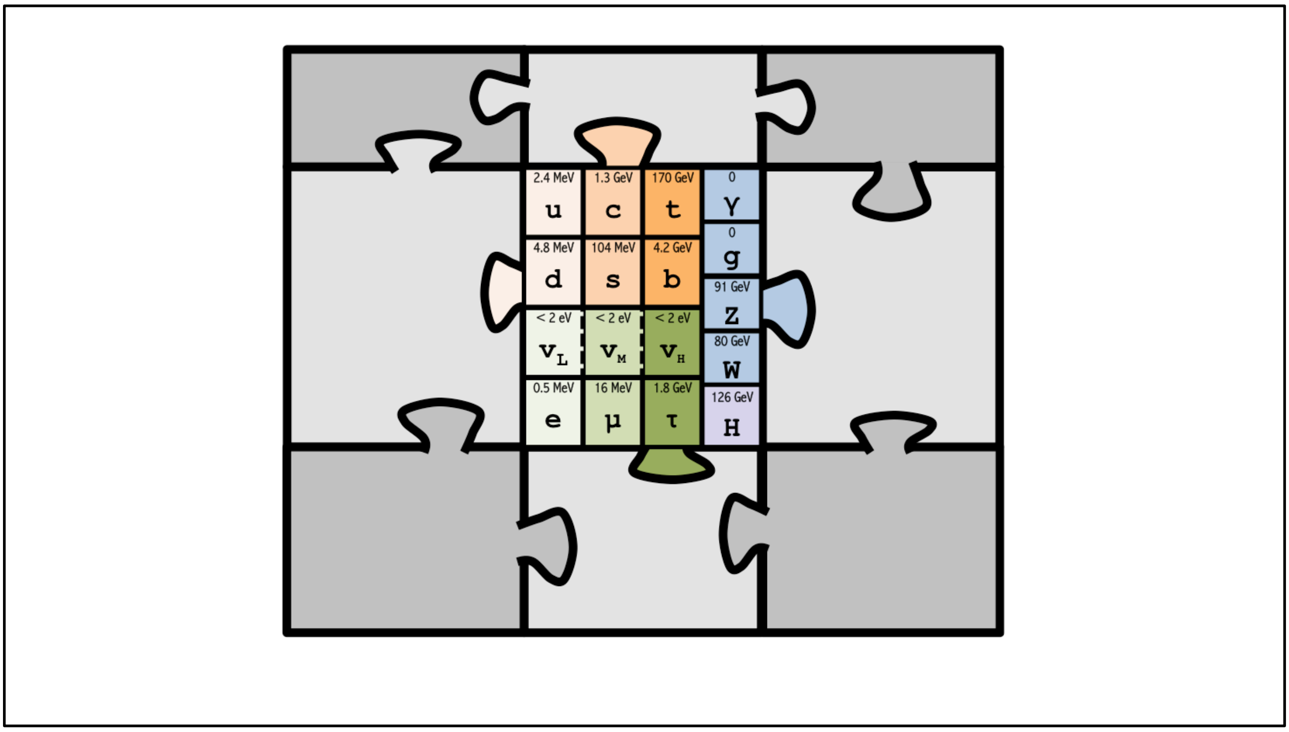
The standard model is our starting point.
It describes the world as we know it today, introducing matter particles and force-carrier particles, the gauge bosons. Matter and forces have been introduced in Module 1 and detailed in Modules 4 to 6.
All these particles have been observed experimentally, the last one being the Higgs boson a few years ago, as explained in Module 6.



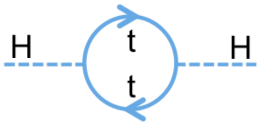
The precision with which the Standard Model describes our world is really astonishing.

For example here you can see a representation of the cross sections with which various processes occur at the LHC, measured by the ATLAS experiment for various center-of-mass energies of the colliding protons.

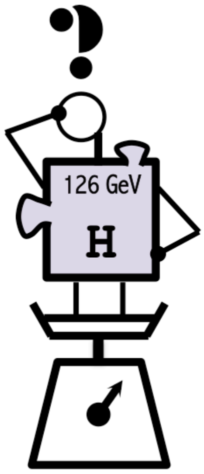
More importantly, note how these compare to the Standard Model theoretical prediction represented by the solid lines.
For a huge range of production rates, the theory agrees surprisingly well with the measurements on collision data.



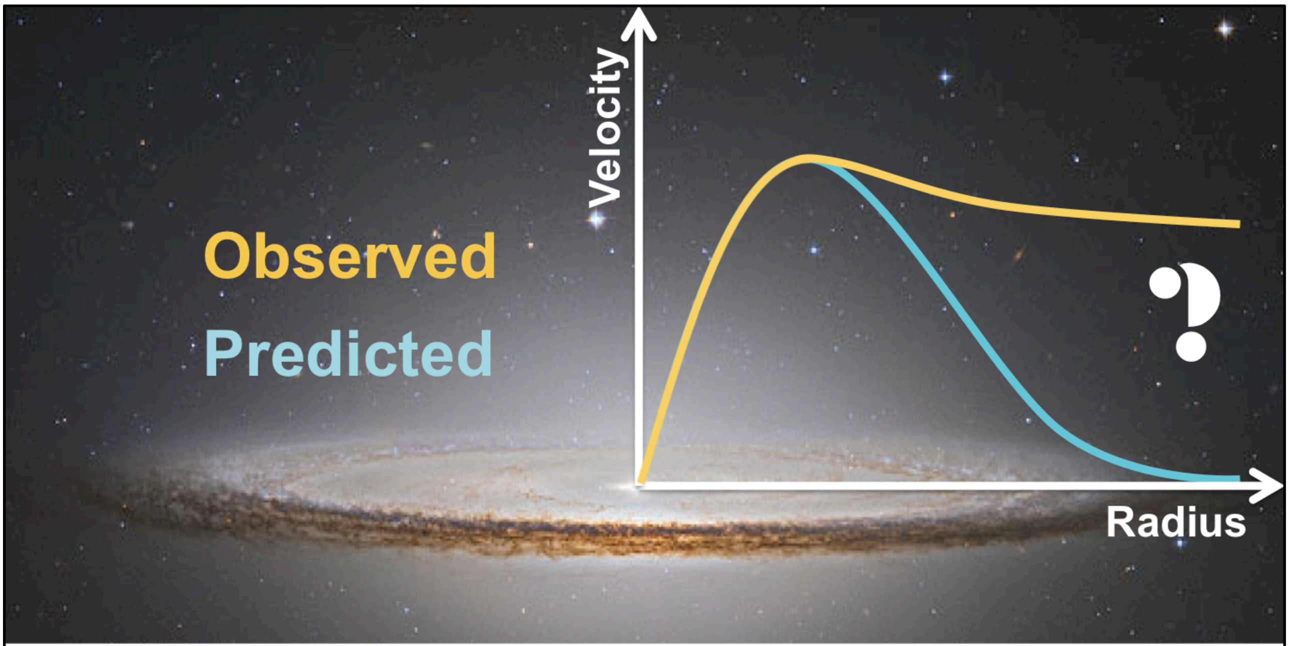
Despite its great success the Standard Model remains a piece in a bigger puzzle. It leaves in fact many questions unanswered.



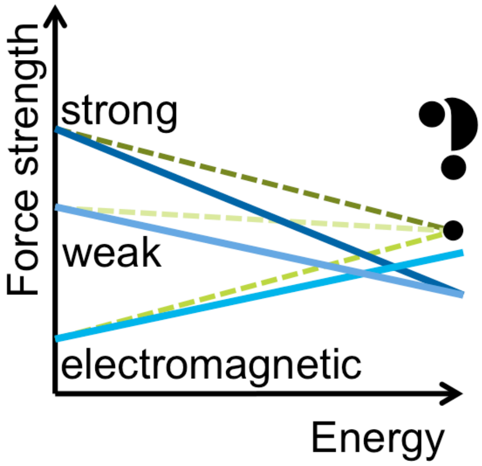
$$m_H^{SM} = m_0 + \alpha + \beta + \ldots \gg 126\mathrm{GeV}$$



The Standard Model does not explain why the Higgs Boson is measured to be so light. Quantum corrections to its propagator, like the one shown here, ought to push its mass to much higher values.

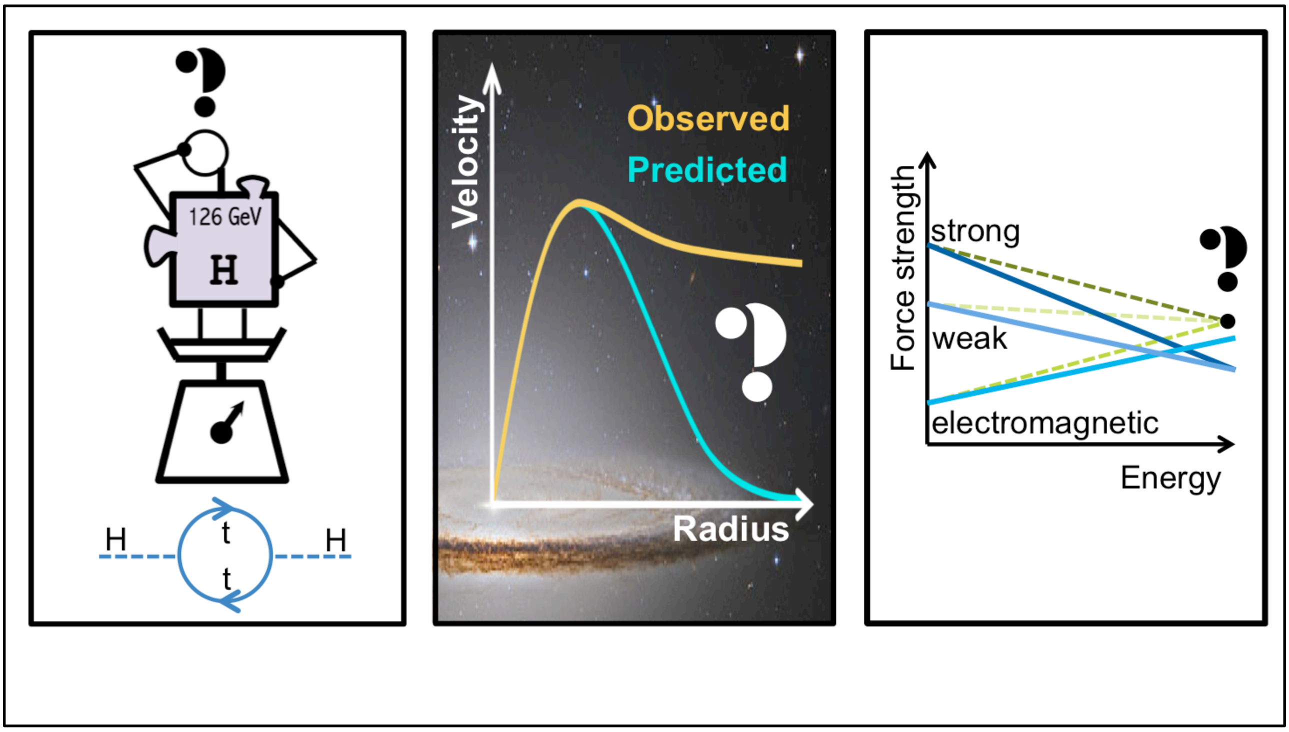


The Standard Model does not explain the observation that the stars in the outskirts of the galaxies rotate much faster compared to theoretical predictions, which indicates the existence of a new form of matter, the dark matter. The dark matter will be explained in video 8.2.

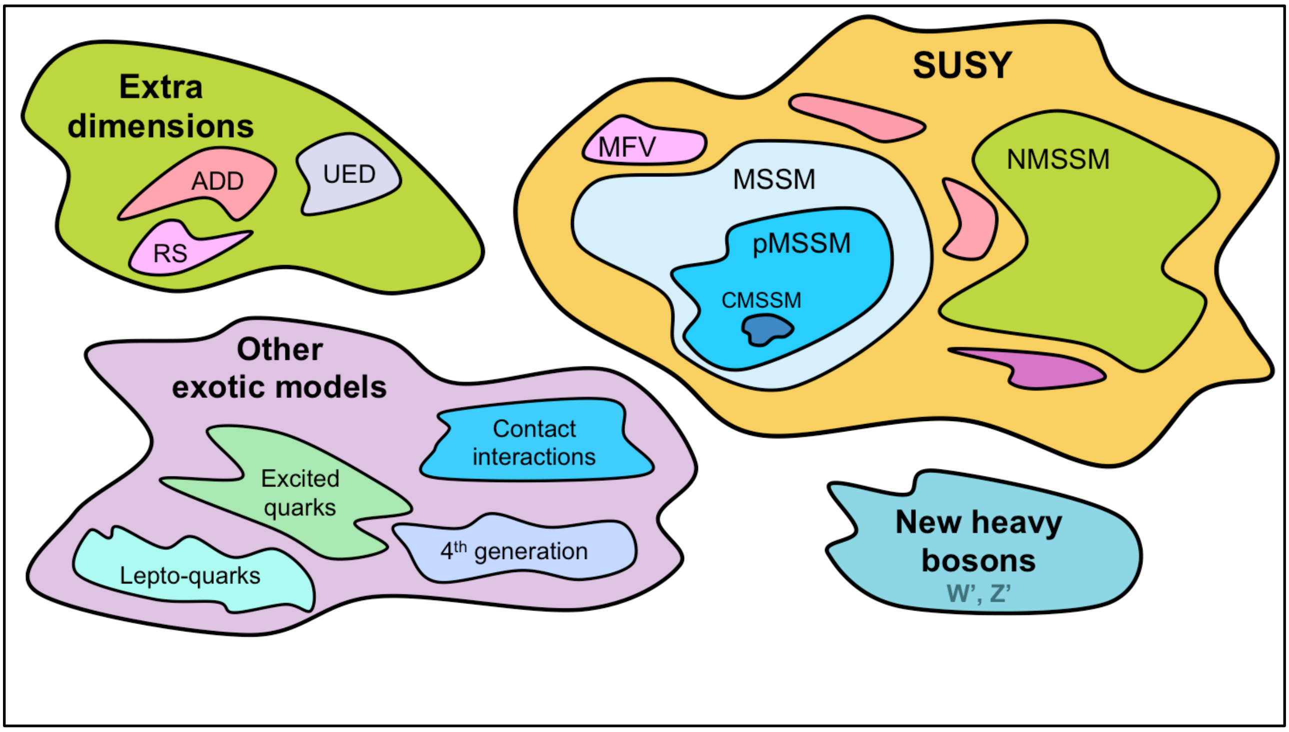


Experiments show that the weak and strong forces become weaker and that the electromagnetic force becomes stronger as the energy increases. We have introduced this phenomenon in video 5.4. This is a good indication that at incredibly high energies, the strength of the electromagnetic, weak and strong forces is probably the same.

The standard model, however, does not provide a unification of these forces at very high energies. What is really happening there?



A lot of thought has been given to these and other problems the Standard Model comes with and ways to mitigate them have been attempted by theorists all over the world.



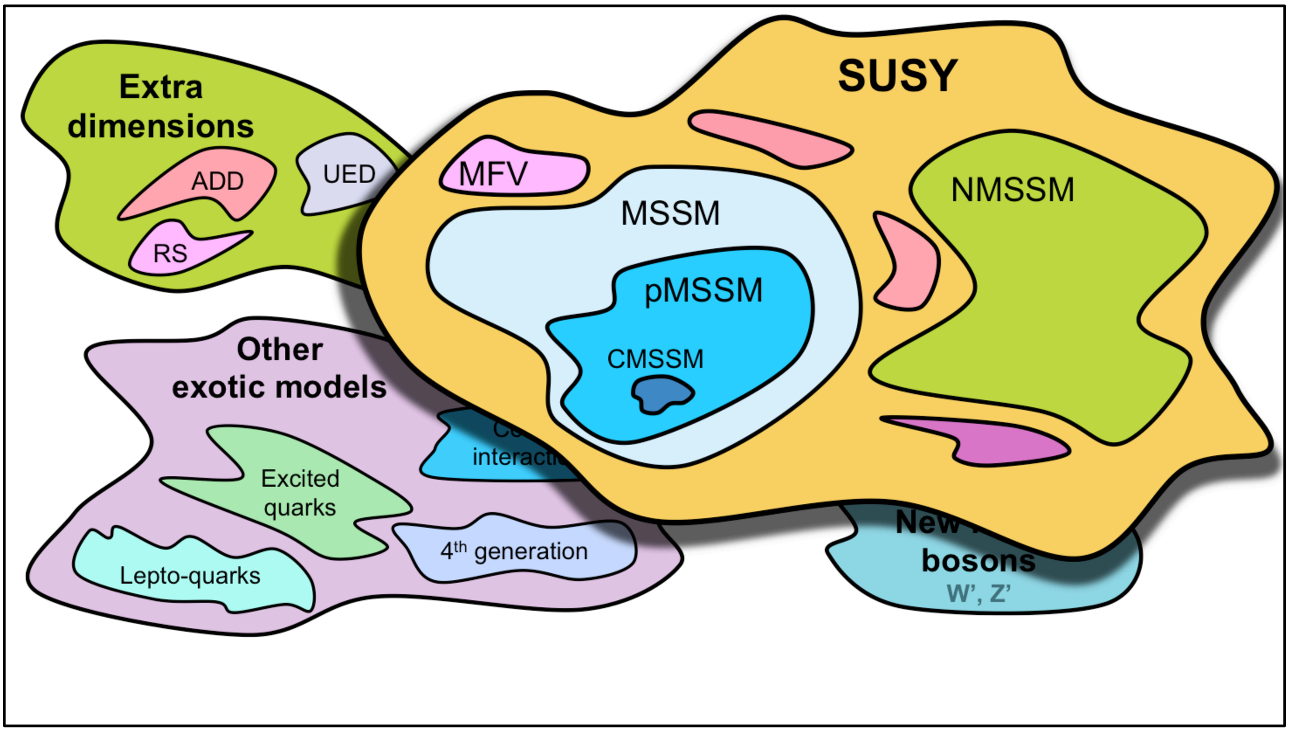
Theorists have come up with many theories or models (in many variants), trying to address one or more problems of the Standard Model at a time.

In some of them, they introduce extra space-time dimensions as a way to explain why gravity is a much weaker force than the other fundamental forces. In such theories, hypothetical force-carrier particles called "gravitons" could be disappearing into extra dimensions after having been created, for example, at a proton-proton collision at the LHC.

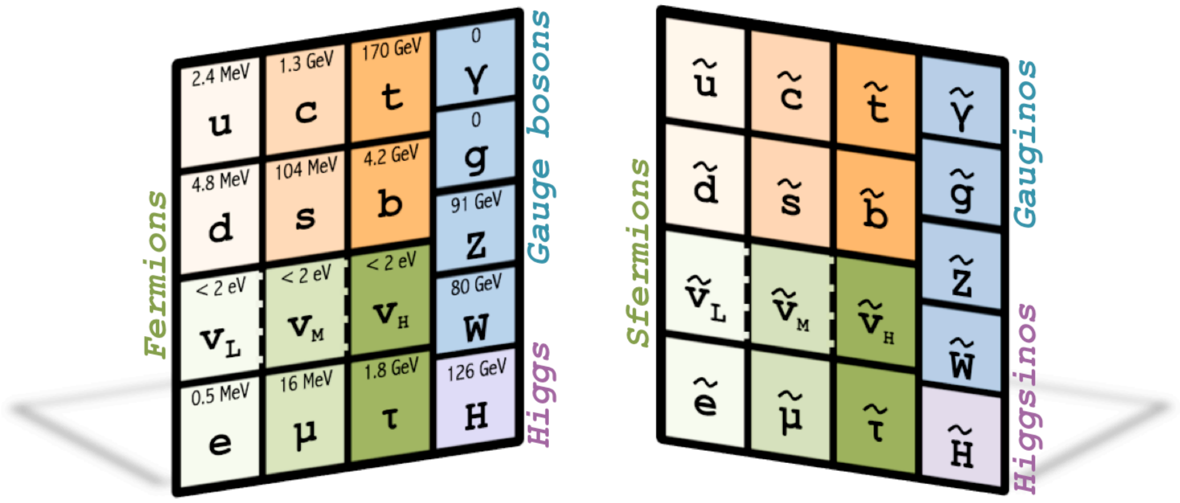
There are many other theories or models that introduce new particles or interactions.

Common in many of those theories is the presence of new heavy bosons, similar to the W and Z bosons, denoted as W' and Z'. How we search for a Z' boson will be explained in the video 7.3.

A large theoretical framework of beyond the standard model physics that has been developed in the last decades is supersymmetry, aka "SUSY".

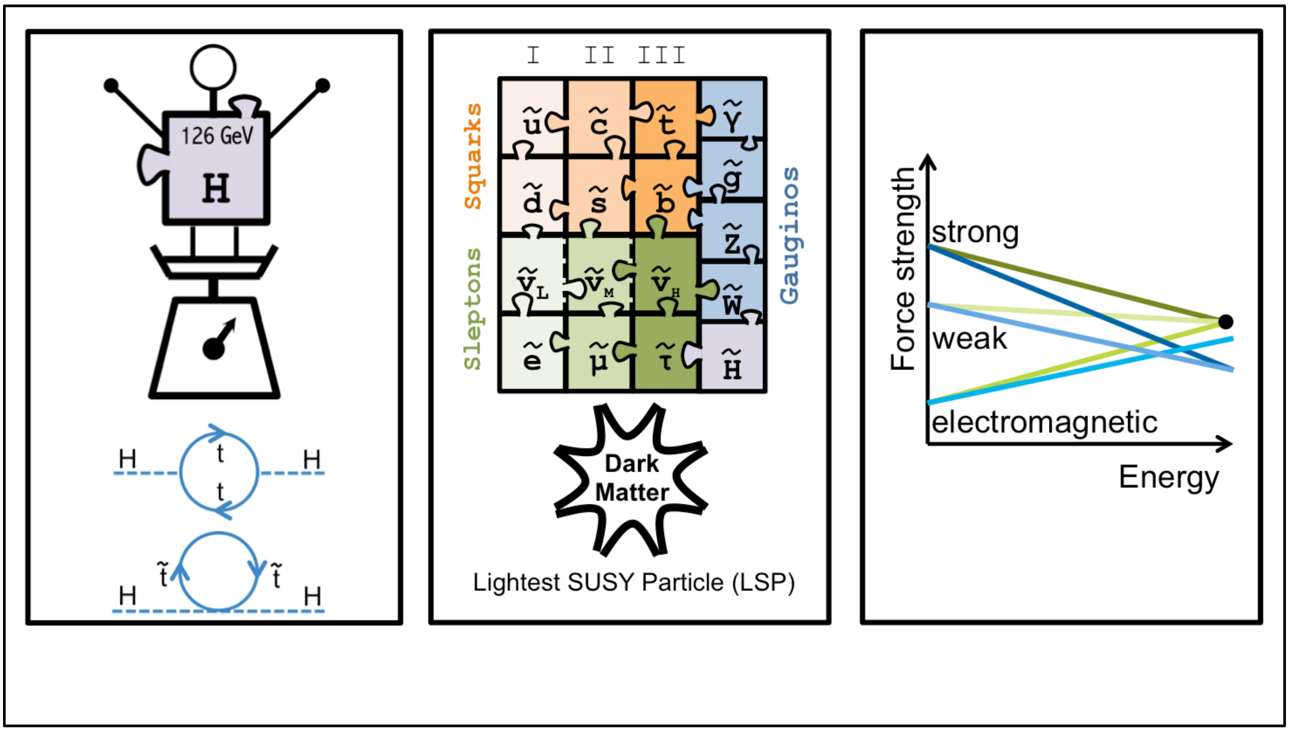


Supersymmetry is one of the most discussed and studied extensions of the standard model.



Forces ⇔ Matter

It imposes a symmetry between the spins of forces and matter, which does not exist in the Standard Model; the Standard Model only has fermionic matter and bosonic forces. This symmetry requires that there be a supersymmetric partner to all particles in our periodic system, their so-called “super-partners”. However we already know that supersymmetry is a badly broken symmetry: the super-partners, if they exist at all, must have different masses than the known particles of our periodic table.

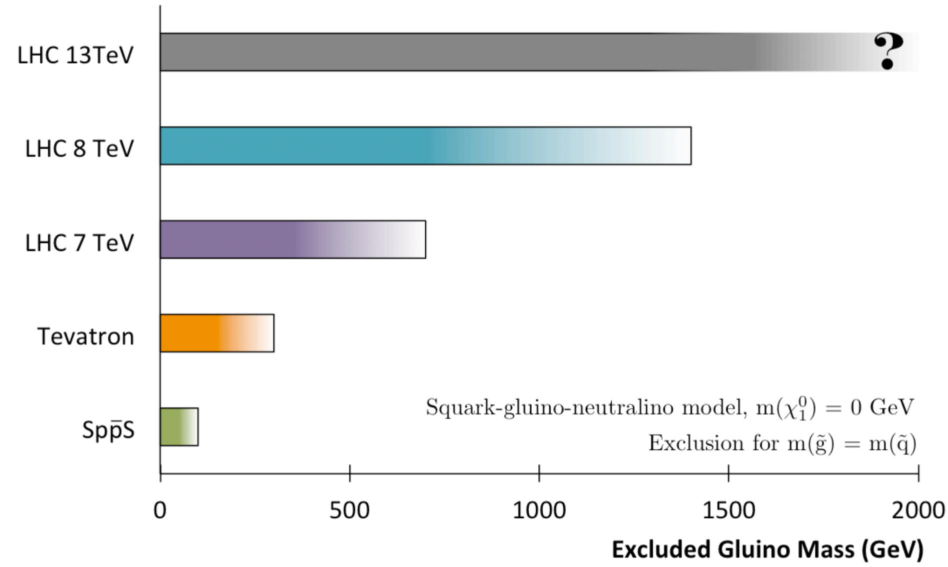


Supersymmetry is supposed to be solving all of standard model's problems at once.

Let's take the first open question we talked about; the Higgs mass problem. The calculation of the Higgs mass within SUSY has extra loop terms coming from the extra particles it introduces. These terms would cancel the large terms in the calculation, leading to a Higgs mass compatible with the experimental result.

The lightest super-partner can be neutral, stable and weakly interacting with matter, becoming a perfect dark matter candidate.

And if supersymmetric particles were included in the Standard Model, the strengths of its three forces – electromagnetism, the strong and weak forces – could have the exact same strength at very high energies, as in the early universe.



Supersymmetric particles have been searched for at lepton and hadron colliders for many decades now, but they remain elusive. We show here limits for the mass of the gluino, the superpartner of the gluon, obtained in a specific supersymmetric model at the latest three generations of hadron colliders.

The available parameter space for supersymmetry becomes increasingly constrained by the experimental findings. The case is similar for many new theories and models. Despite the fact that there are no hints for new physics in the collider experiments today, the urge to find new physics is always present and it is the reason why high energy physicists keep on seeking an anomaly in the data.

This concludes the first video of this 7th module. In the next video we will describe the tools physicists are using to make sense of the data collected at hadron colliders in order to produce physics results and search for new phenomena.