

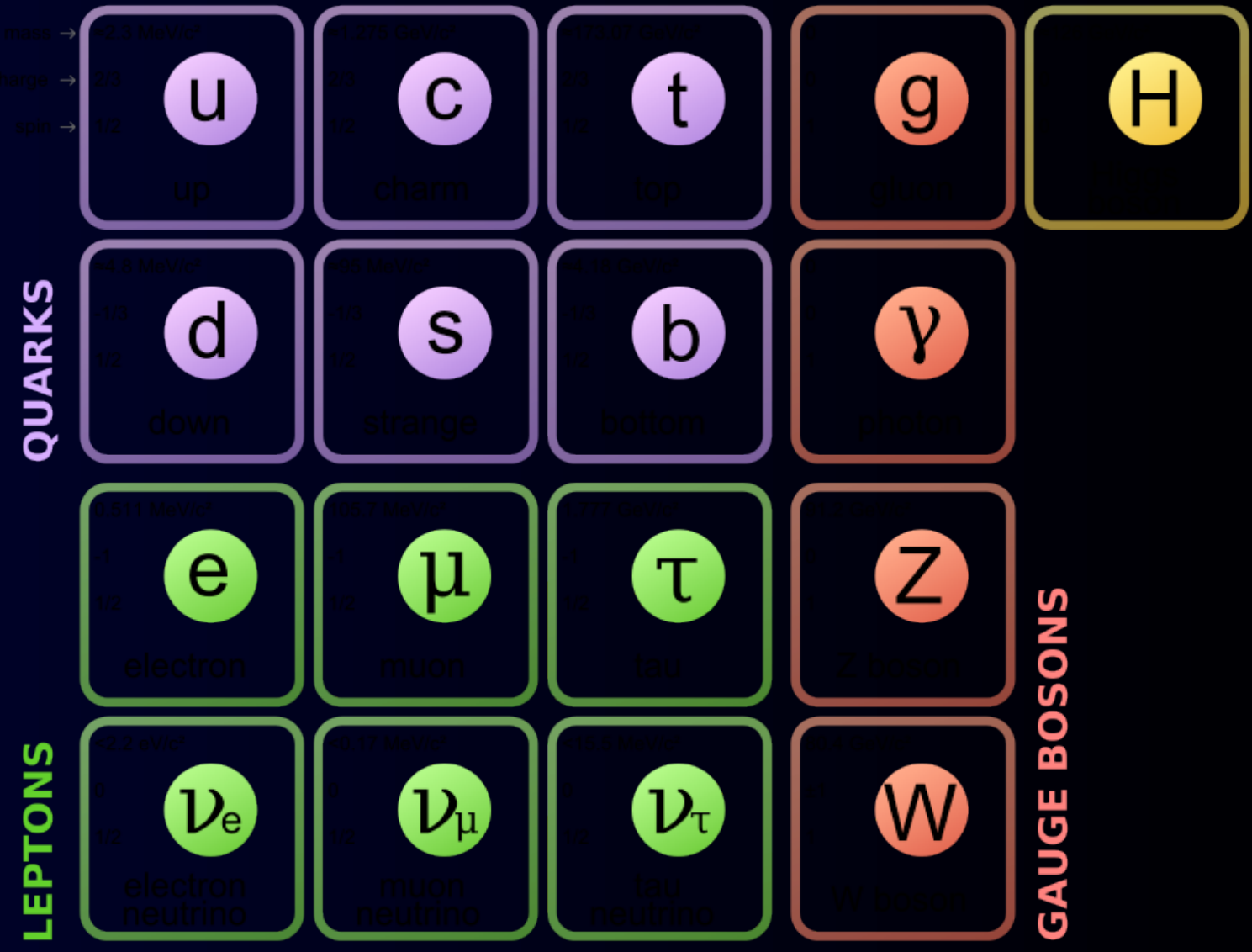
The Standard Model of Elementary Particles

What are we made of?

Everything around us is made up of **elementary particles**, for instance the **quarks** within **protons** and **neutrons** in atomic nuclei, and the **leptons**, like the **electrons** which orbit around nuclei. Together they form the atoms which are constituents of matter. There are **3 families** of quarks and leptons, with identical properties, except for their enormously different masses.

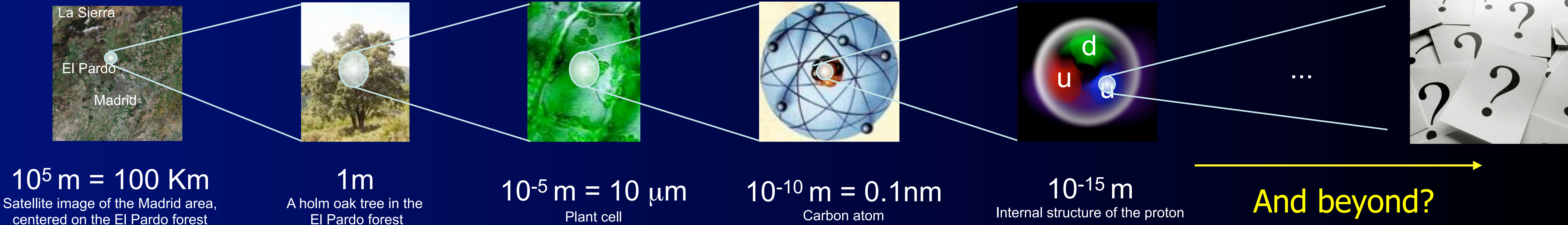
What holds particles together?

Elementary particles are subject to forces associated to **four fundamental interactions**: **electromagnetism**, the **strong force**, the weak interaction, and **gravity**. Each one of these interactions is associated with one or several force particles, the **gauge bosons**: the **photon**, the **Z y W bosons**, the **gluons** and the (still hypothetical) **graviton**.



The Higgs boson

The mass of elementary particles arises from their interaction with the **Higgs field**, which permeates all of space and time, and whose interactions with particles contributes to their internal energy, i.e. their mass. The fluctuations of the Higgs field itself correspond to a new kind of particle, the **Higgs boson**, discovered in 2012 in the Large Hadron Collider LHC at CERN in Geneva.



Intense activity in theory...

... and experiment

Supersymmetry (SUSY)

Supersymmetry proposes that **for each particle of the Standard Model there exists a partner particle** with the same charges, but different spin and much larger mass. These masses would be within the energy reach of the LHC, which could potentially discover supersymmetric particles (**squarks, sleptons, gluinos, photino, Wino, Zino and Higgsinos**)

Supersymmetry would partially solve the **hierarchy problem** (see “Open puzzles” below). Also, the lightest supersymmetric particle could explain the dark matter of the universe. Finally, supersymmetry is intimately related to gravity (in theories of **supergravity**) and arises naturally in string theory.

Composite models

In analogy with protons and neutrons being composite particles made up of other more fundamental ones (quarks), **composite models** suggest that particles considered to be elementary (quarks, leptons, the Higgs boson,...) could well be composites of other smaller particles. These more elementary particles would be confined by a new set of interactions, much more intense than any other known force.

A composite Higgs boson would provide a solution to the hierarchy problem in a way alternative to supersymmetry. Composite models predic that composite particles should be accompanied by a spectrum of massive resonances, which could be discovered at the LHC.

LHC: el gran colisionador de hadrones

El LHC es un acelerador del CERN, en la frontera franco-suiza cerca de Ginebra. Hace circular protones por un túnel circular de 27km enterrado a 100m bajo tierra, los acelera a velocidades próximas a la de luz y los hace colisionar en el centro de sus detectores.

Los detectores ATLAS y CMS, de dimensiones descomunales pero de exquisita precisión, detectan los productos de las colisiones. Los millontes de Gigabytes de datos se analizan en uan red de ordenadores distribuida en centros de investigación de todo el mundo.

Los resultados del LHC permiten explorar la frontera de las altas energías, someter a comprobación experimental las diferentes propuestas más allá del Modelo Estándar, y muy posiblemente descubrir nuevas partículas y simetrías que definan nuestro conocimiento del mundo subatómico a un nivel más profundo.

Grand Unification Theories (GUTs)

The strengths of electromagnetic, weak and strong interactions become essentially equal when they are extrapolated to very high energies. **Grand Unification Theores (GUTs)** propose that the different interactions we observe are different manifestations of a unique forces, out of which they arise via spontaneous symmetry breaking (similar to the Higgs field mechanism).

The unification of interaction strengths is more precise in the context of supersymmetry, motivating **SUSY-GUT** models.

(SUSY) GUTs predict **proton decay** mediated by very massive interaction bosons. Although the expected proton lifetime is exceedingly long, there are experiments actively looking for events signalling the instability of the proton.

Extra Dimensions

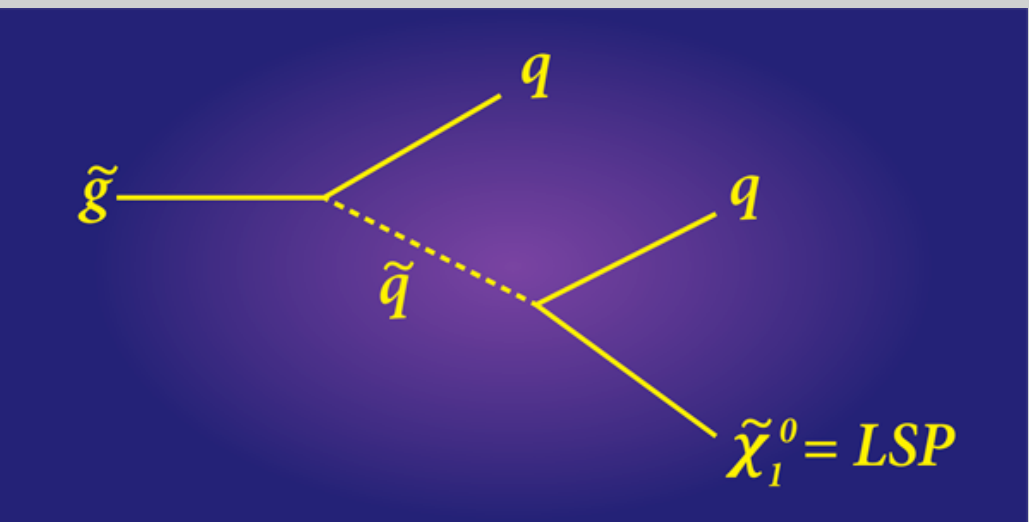
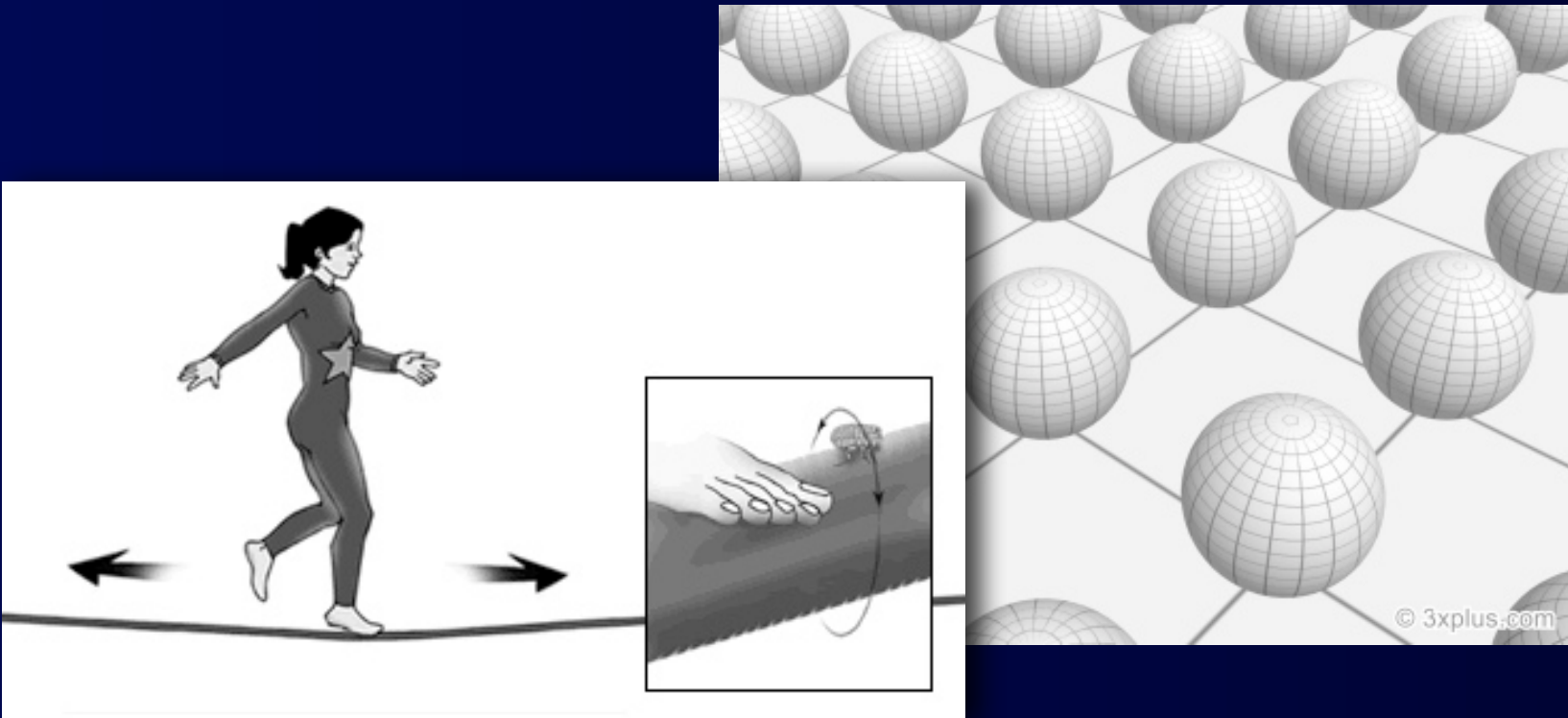
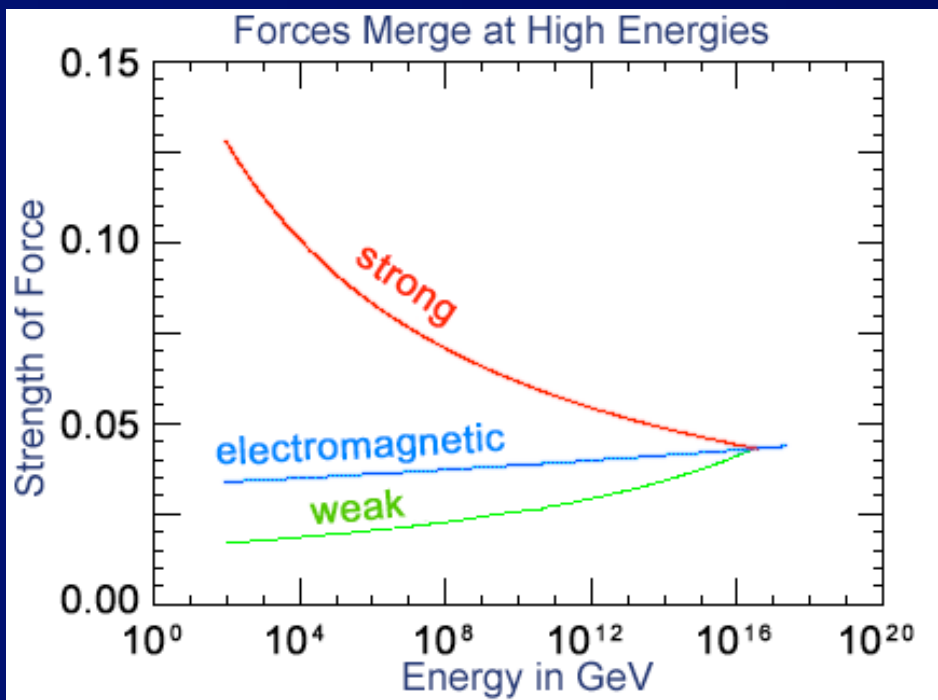
In certain models (like in string theory), besides the 3 spatial dimensions of our daily experience, there exist **additional dimensions** playing a role in Particle Physics. The extra dimensions would be curled up with a very small size, and would only be accessible at very high energies (namely, with experiments of very high spatial resolution).

In certain models, the extra dimensions could be discovered at the LHC, by the detection of massive resonances of known particles, or processes with “missing energy”, in which particles escaping into the extra dimensions are responsible for the non-detection of part of the collision energy.

Dark matter particles

The presence of a **dark matter** density in the universe could be explained in terms of a fluid of some still unknown particle. These particles should be stable, uncharged, and with very feeble interactions with ordinary matter.

Many models of Physics beyond the Standard Model include candidate particles for dark matter, some of which could be discovered at the LHC. A prototypical example is the neutralino, the **lightest supersymmetric particle** or LSP, in many supersymmetric models.



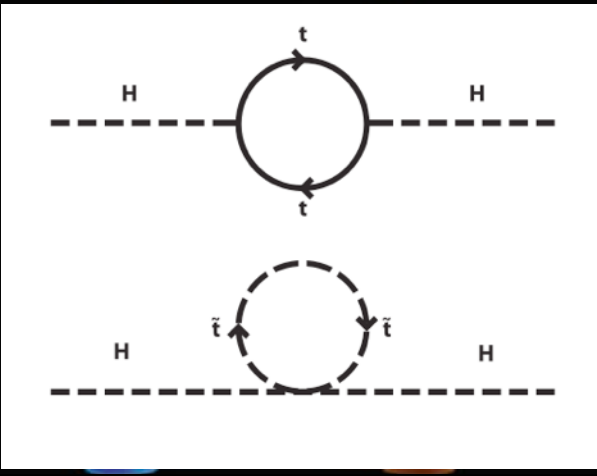
Open puzzles

3 families and their masses



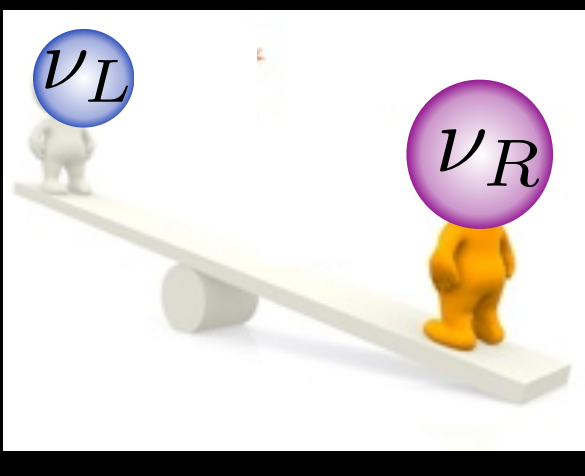
Matter particles (quarks and leptons) come in 3 families with most properties identical (same charges under interactions), but with very different masses. What is the origin of families and the explanation of their mass values?

Hierarchy



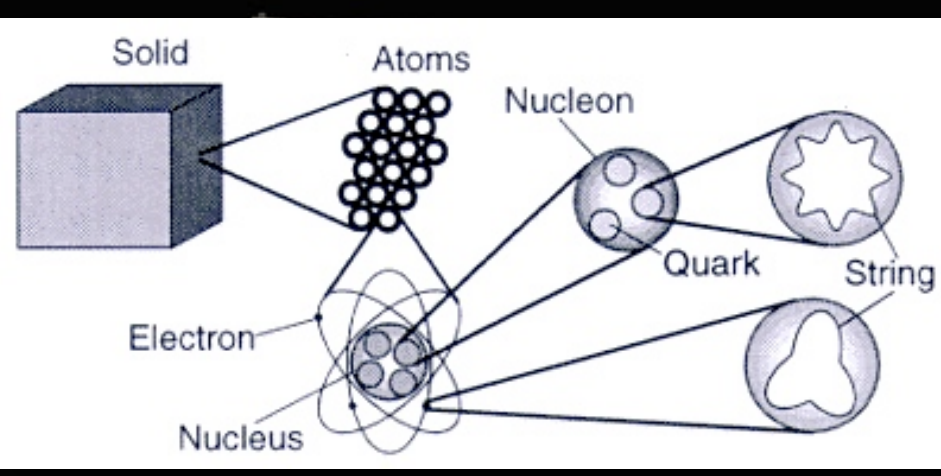
The Higgs boson mass is many orders of magnitude smaller than other scales in Nature, like the Planck scale (which controls gravitational interactions). What is the mechanism underlying this enormous difference?

Neutrinos



Neutrino masses are exceedingly small, but non-zero. To complete the Standard Model to include them, and to explain their tiny mass, the so-called see-saw mechanism proposes still unobserved new kinds of neutrinos with enormous masses.

Gravity and strings



The Standard Model does not include gravity, which we are not able to describe within Quantum Mechanics. String theory provides this description and suggests the possible unification, at extremely high energies, of all known interactions. La teoría de cuerdas proporciona esta descripción, y sugiere la posible unificación, a altísimas energías, de todas las