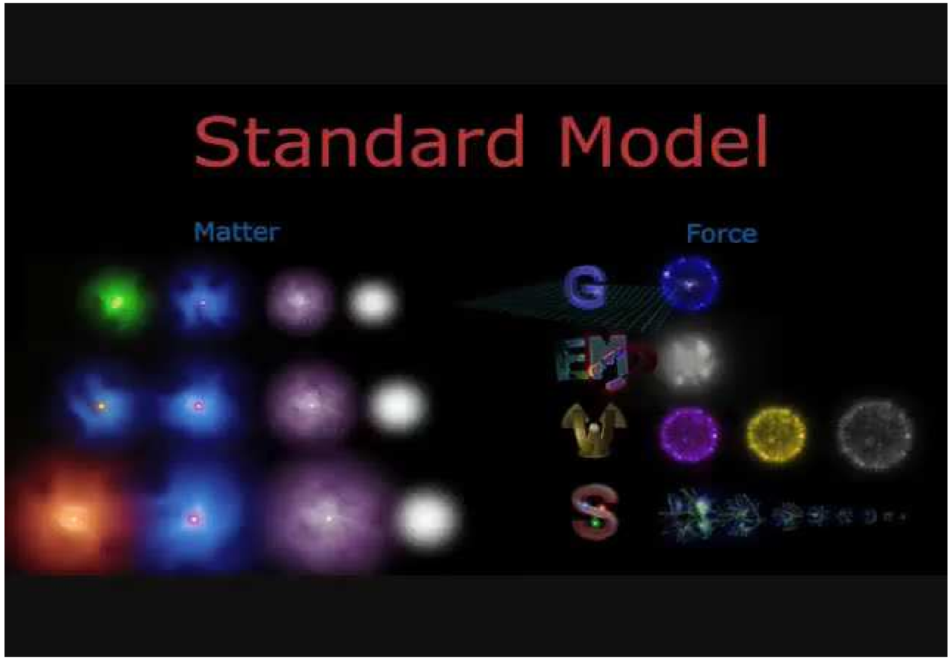
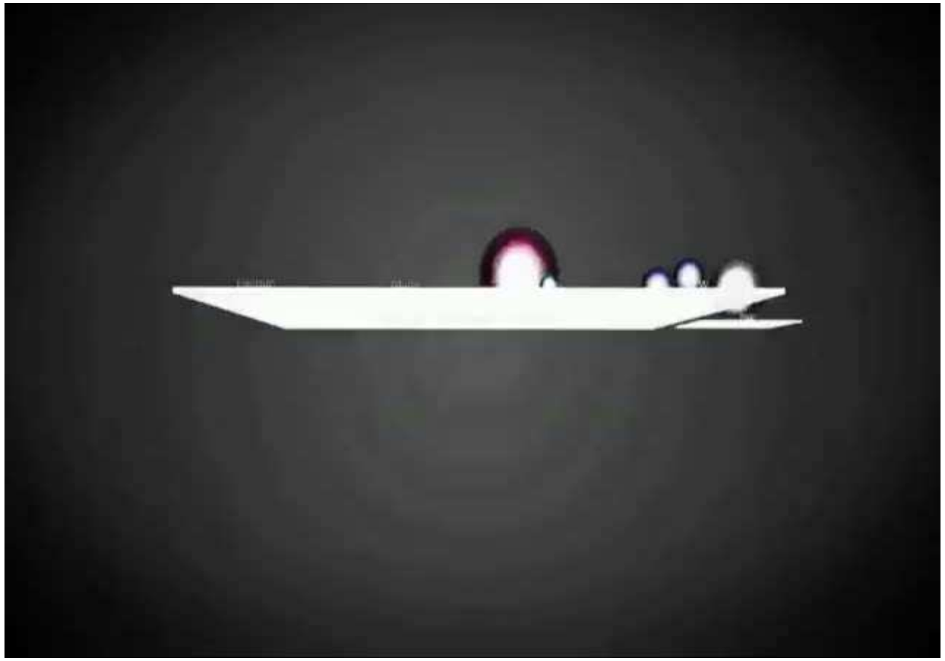




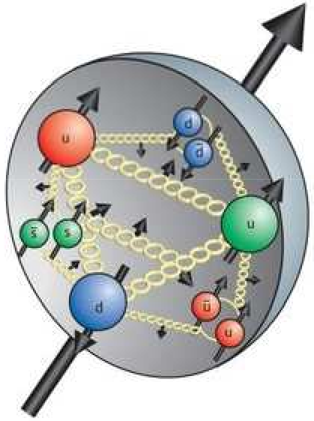
What fundamental knowledge is sought at CERN?

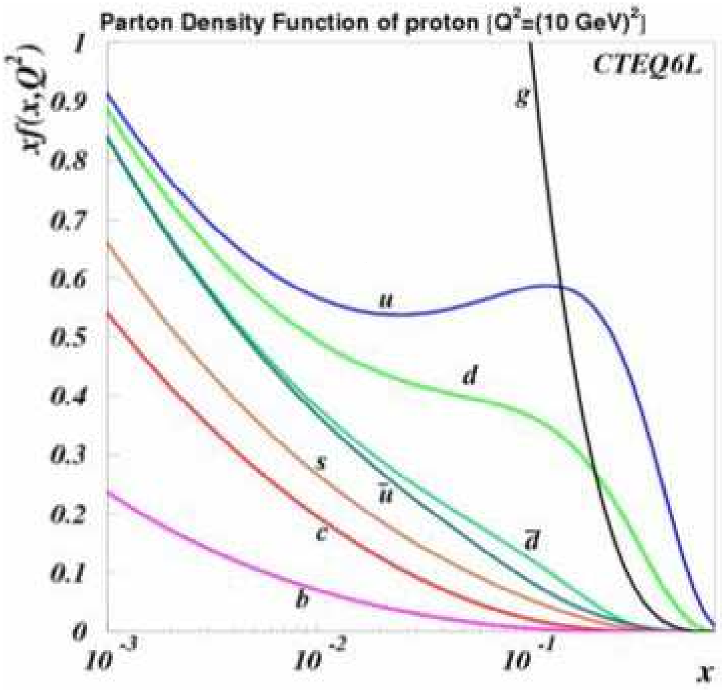
A.Juodagalvis
Institute of Theoretical Physics and Astronomy, Vilnius University

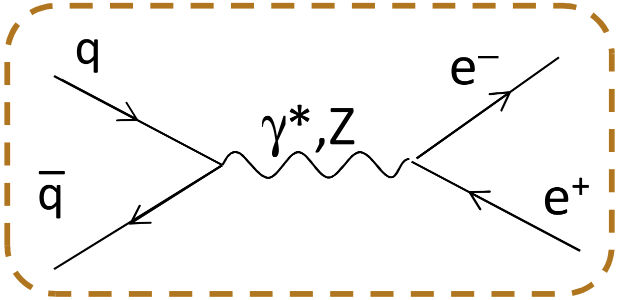
CERN/CMS Computing and Technology Workshop in Vilnius on December 13, 2016

Drell-Yan process

- The existence of the “quark sea” is proven by the Drell-Yan process, namely, the production of lepton-antilepton pairs in hadron collisions







p + p ⟶ e⁻ + e⁺ + X

$$\frac{d\sigma}{dm_{\ell\ell}} \text{ and } \frac{d^2\sigma}{dm_{\ell\ell}\, dy_{\ell\ell}}$$

What is High-Energy Physics?

- Particle physics is the branch of physics that studies the elementary constituents of matter and energy, and the interactions between them.

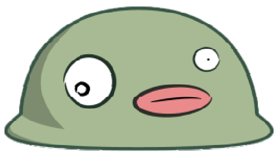
- Murphy’s law: If anything can go wrong, it will.

- Dunlap’s Laws of Physics:
  1. Fact is solidified opinion.
  2. Facts may weaken under extreme heat and pressure.
  3. Truth is elastic.

Universal lego bricks of matter

Quarks

up



down

Lepton

electron

Blueprint:

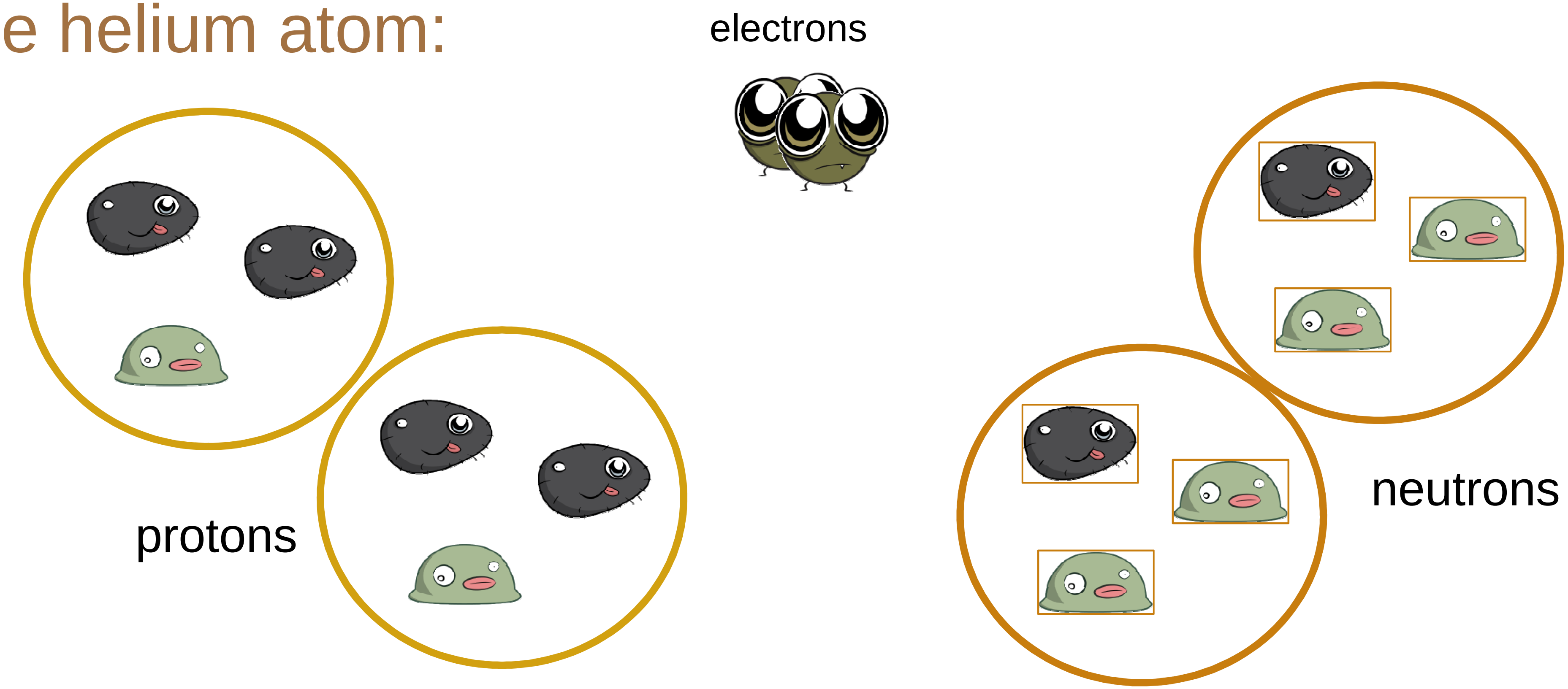
UUD = proton

UDD = neutron

D.Barney (CMS & CERN)

Building an Atom

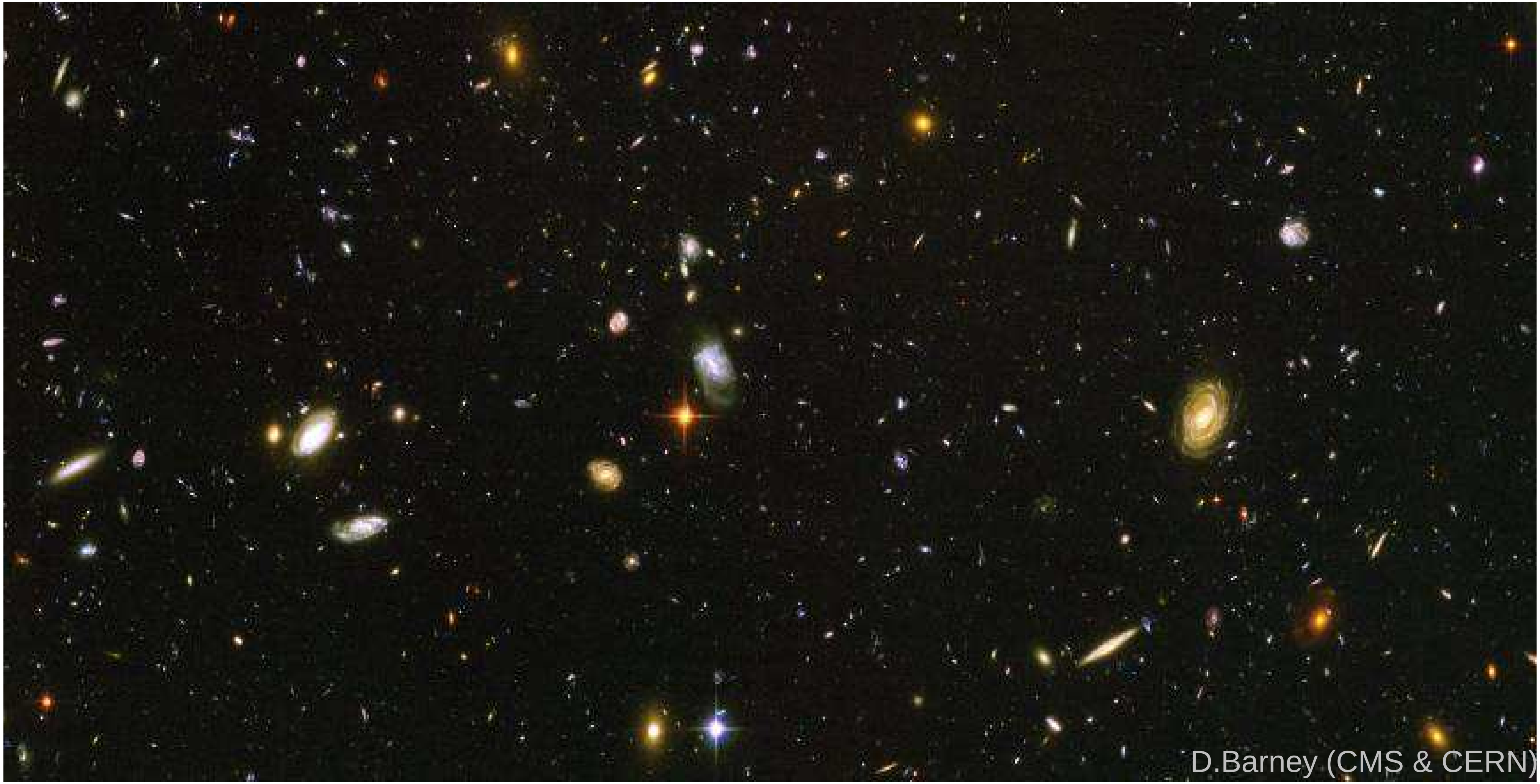
The helium atom:



Multiply by billions and billions and billions and billions…

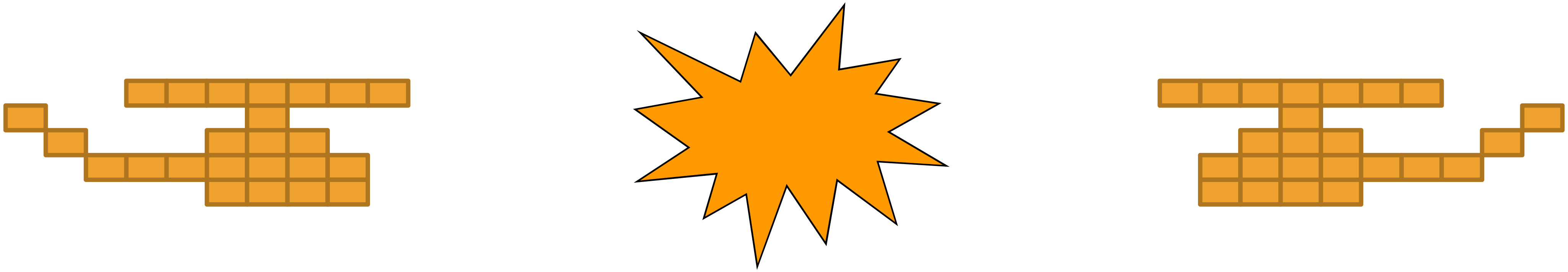
D.Barney (CMS & CERN)

Et voila – the Universe!



This is not a full story...

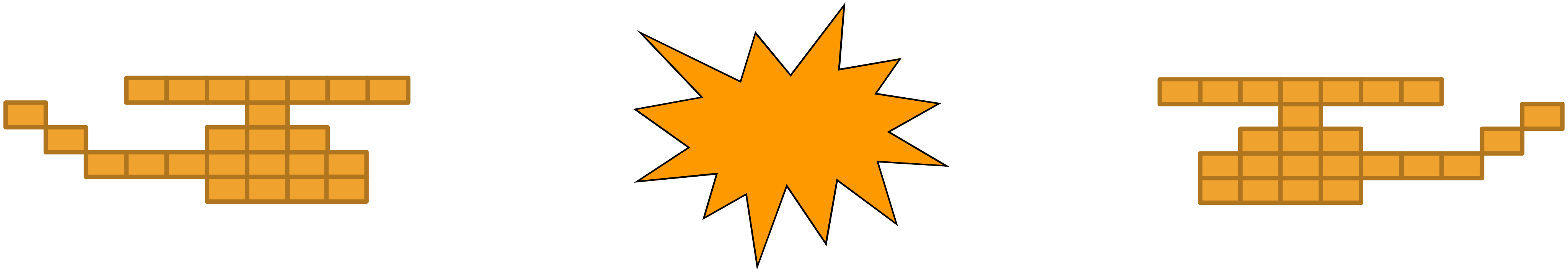
What is expected in a collision?



Collision energy

D.Barney (CMS & CERN)

What is expected in a collision?

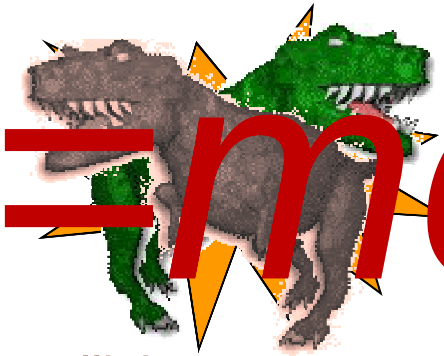


Collision energy

D.Barney (CMS & CERN)

What is expected in a collision *at CERN*?

$$E=mc^2$$



The collision energy was used
to create something new, that
did exist but does not any more!

Collider energy

D.Barney (CMS & CERN)

Proton collision at high energy at CERN

CERN

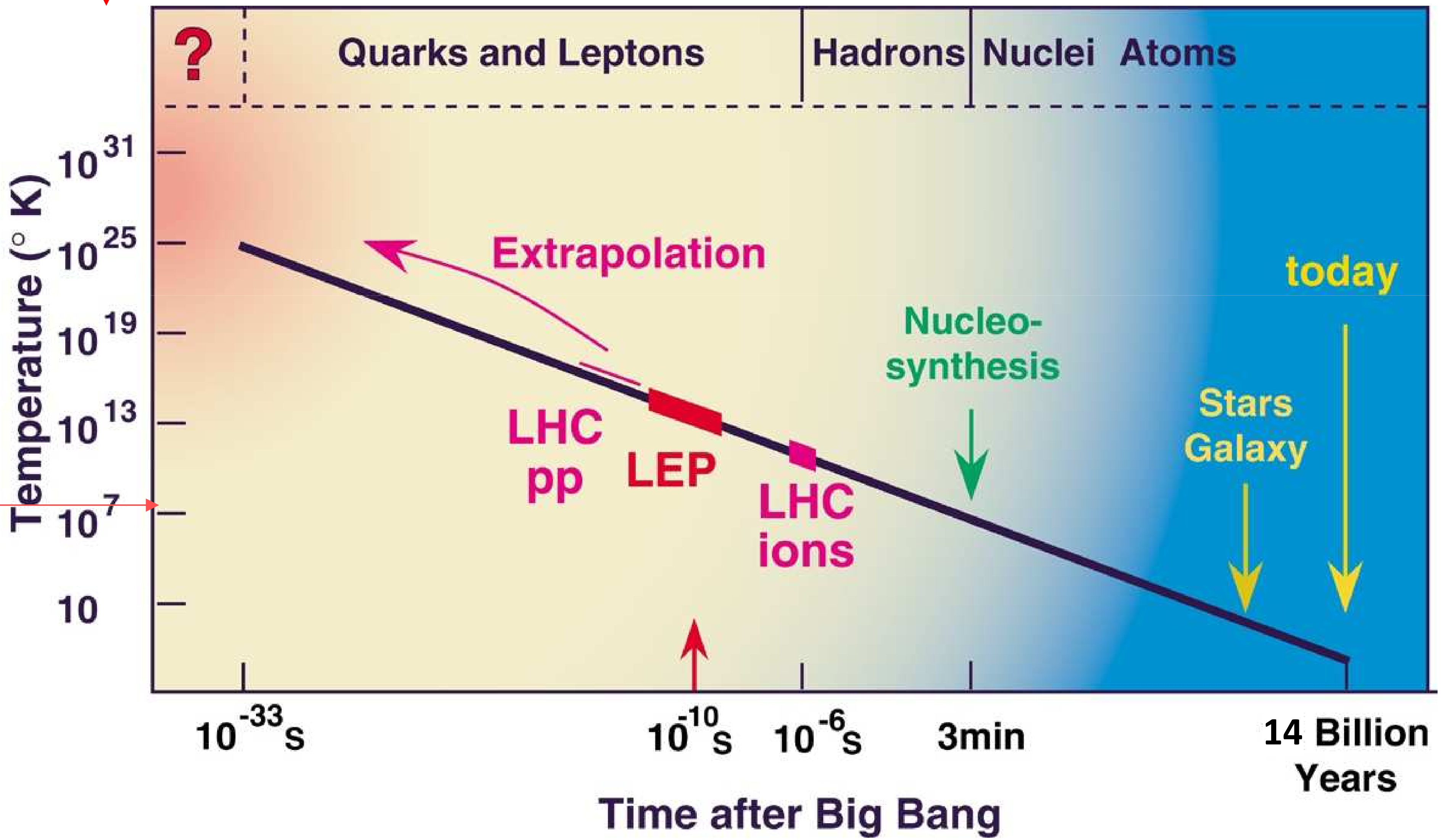
Back to Creation

Metaphysics

Quantum Gravity

Electroweak Transition

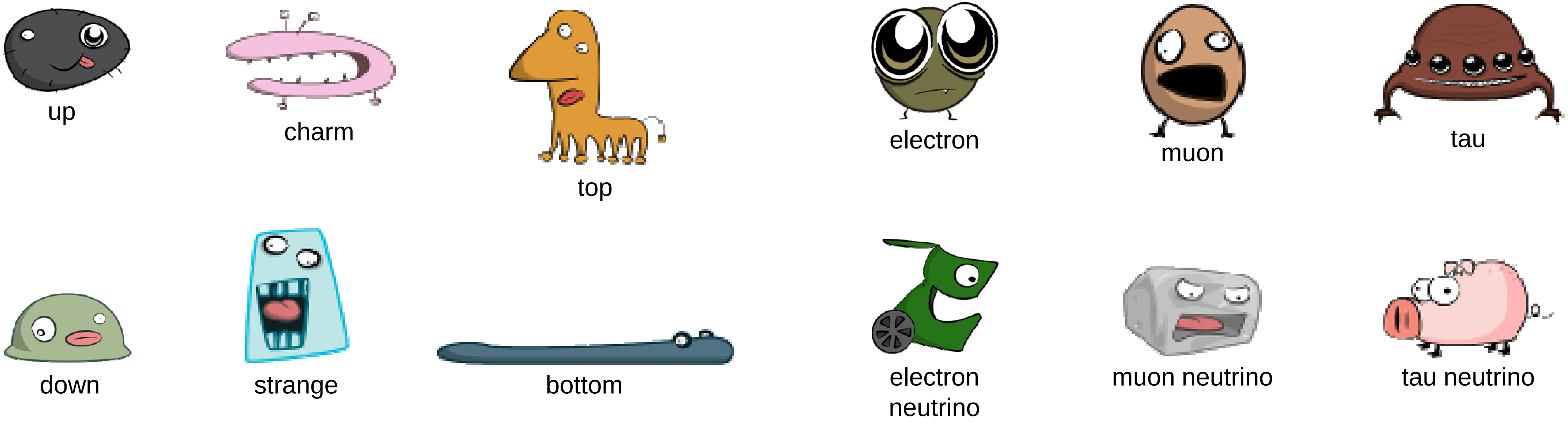
T_{sun}



The story as we tell it now

13.7 billion years ago, there were other things in the Universe…

Quarks | Leptons

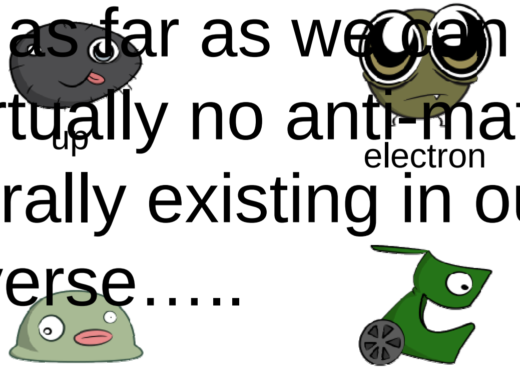


D.Barney (CMS & CERN)

There is also anti-matter….

There is an antiparticle for every type of particle

But, as far as we can tell, there is virtually no anti-matter naturally existing in our Universe…..



Particles and antiparticles have opposite electric charge

D.Barney (CMS & CERN)

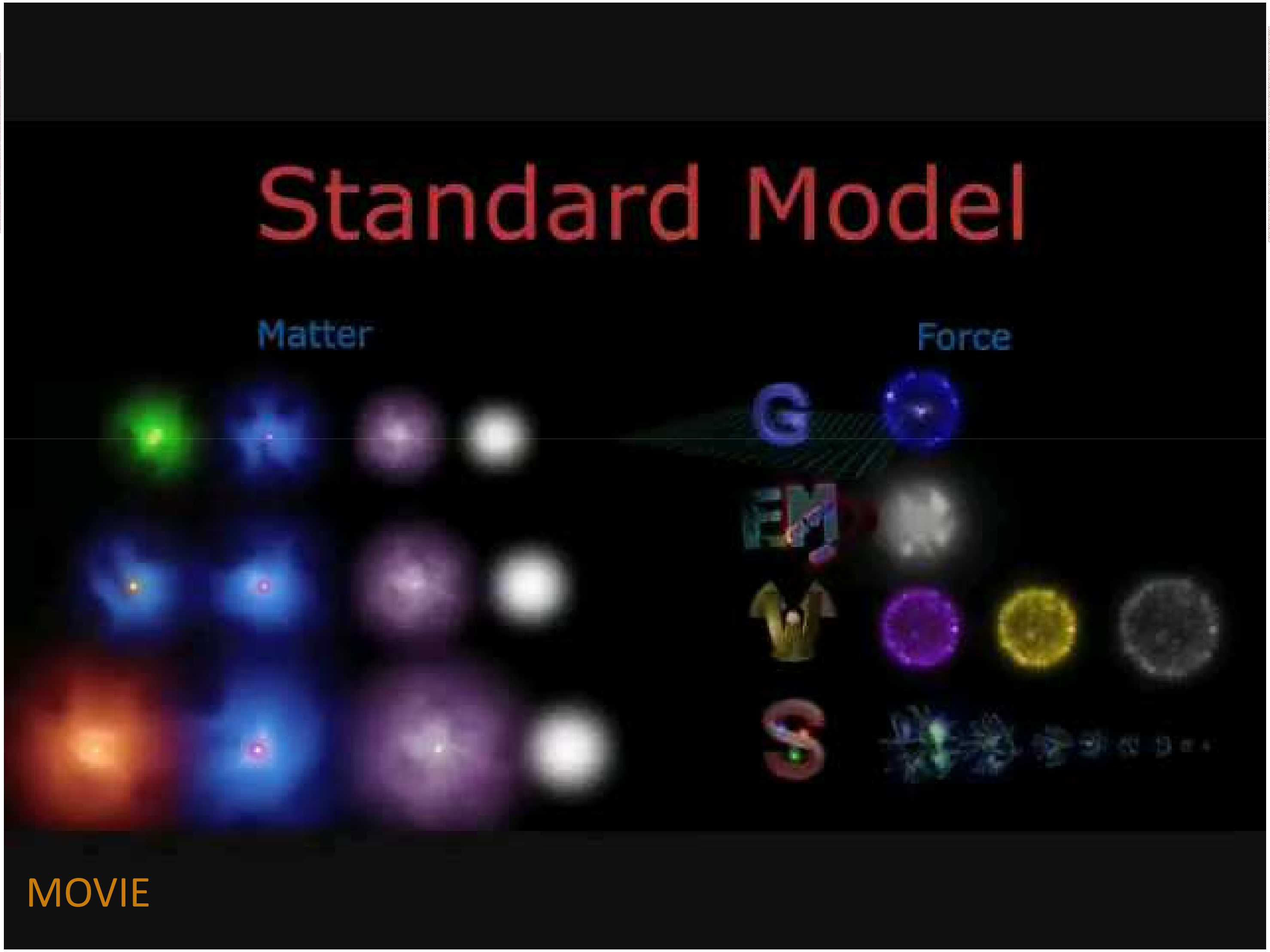
"Periodic table" of fundamental particles

Three families of particles

(stable) I

II

III



quarks | leptons force carriers

Four fundamental forces

- gravitational
- electromagnetic
- weak
- strong

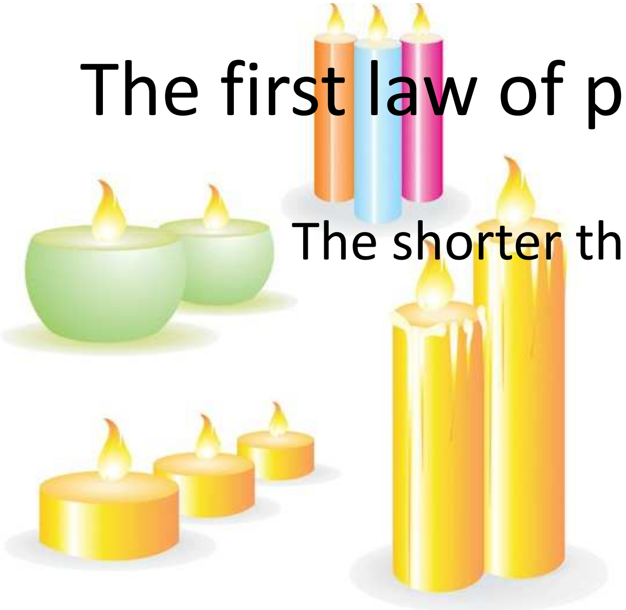
animation: http://www.cassiopeiaproject.com

Why fundamental research is needed?

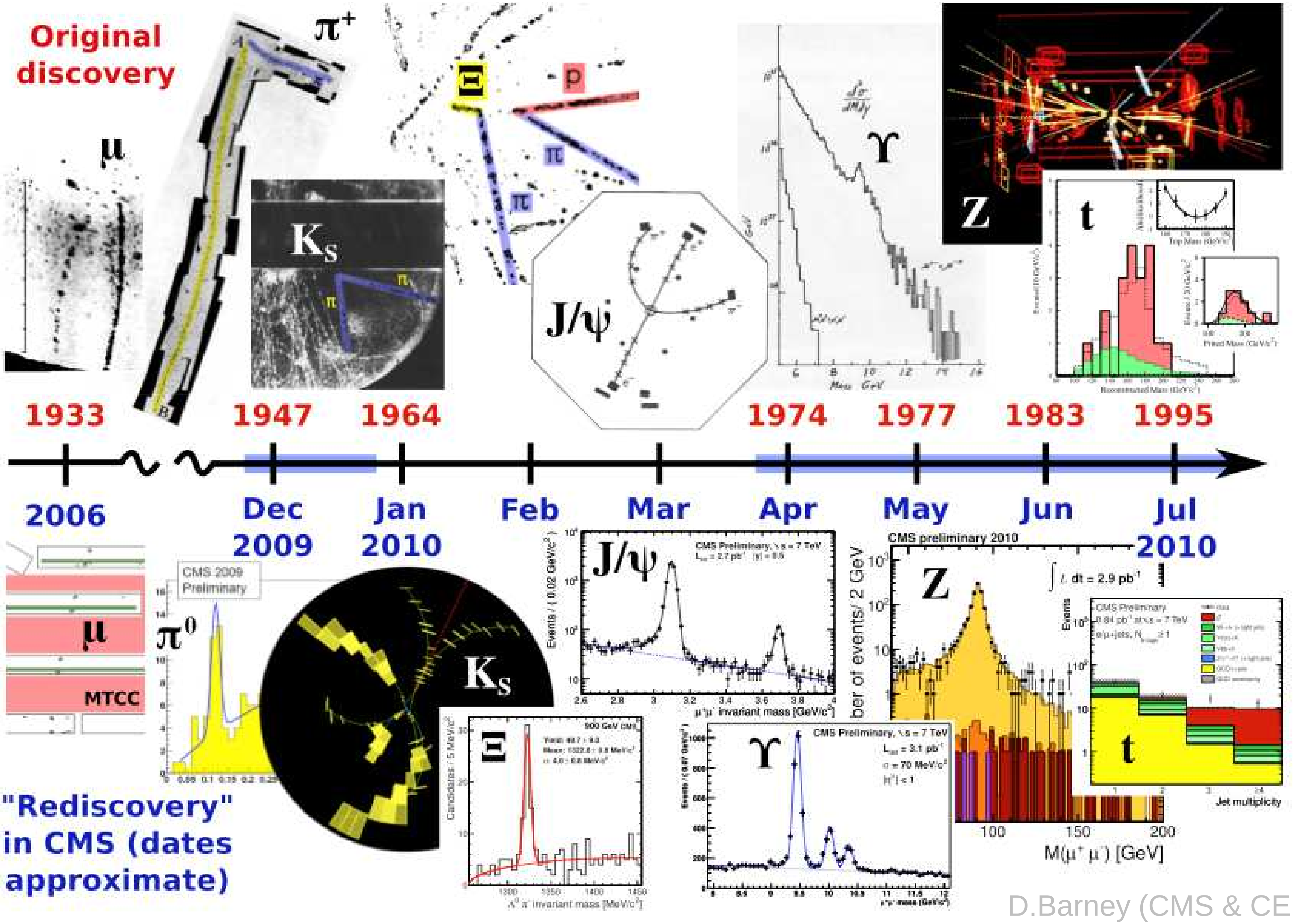
How many improvements are needed?

The first law of particle physics [from Murphy's laws]:

The shorter the life of the particle the more it costs to produce.

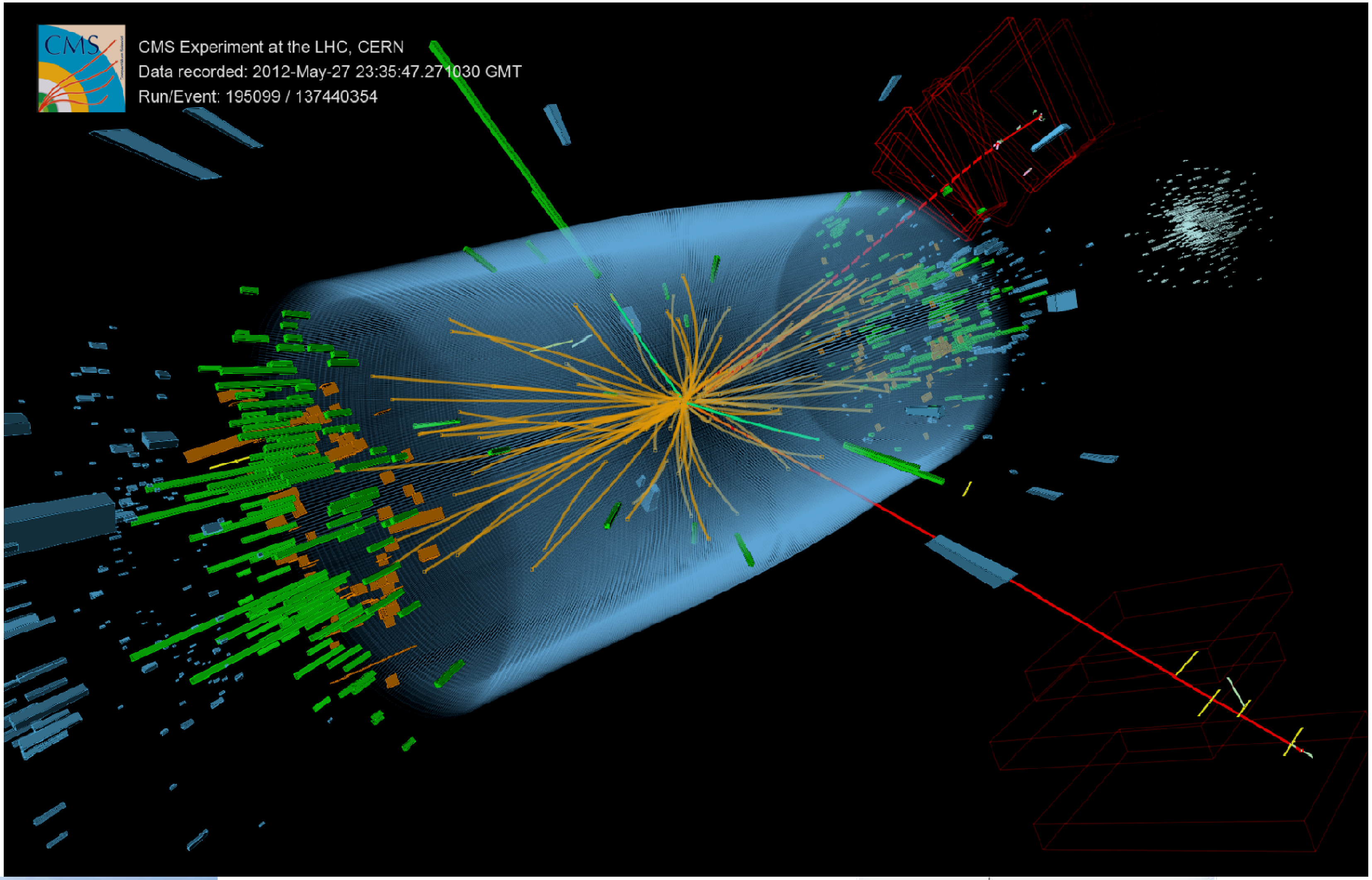


Re-discovery in CMS



D.Barney (CMS & CERN)

Decay of a Higgs boson candidate

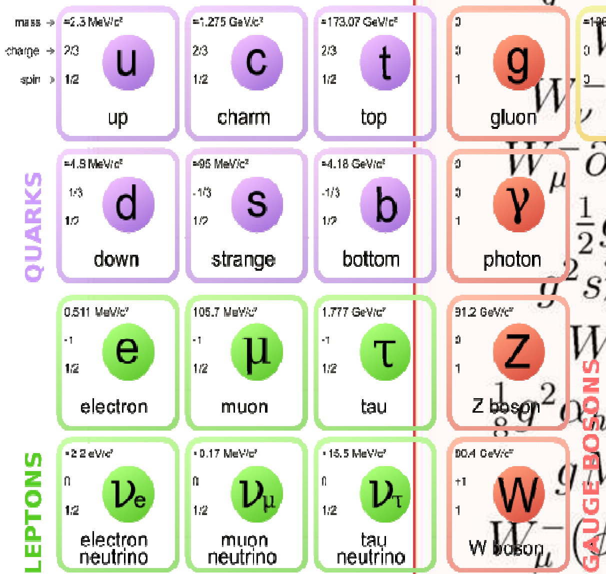


Nobel prize in physics 2013

"... for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

F.Englert and P.W.Higgs

Standard model in formulas



MissMJ, http://en.wikipedia.org

1

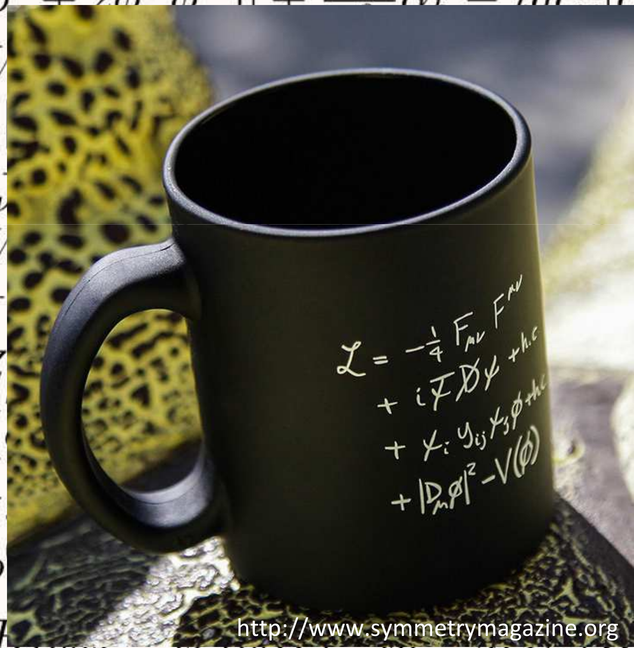
$$-\frac{1}{2}\partial_\nu g^a_\mu\partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu +$$

$$\frac{1}{2}ig_s^2(\bar{q}_i^\sigma\gamma^\mu q_j^\sigma)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu\partial_\nu W^-_\mu -$$

2

$$M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu\partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu\partial_\mu A_\nu - \frac{1}{2}\partial_\mu H\partial_\mu H -$$

$$\frac{1}{2}m_h^2 H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - M^2\phi^+\phi^- - \frac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h\left[\frac{2M^2}{g^2} +\right.$$



$$igs_w M A_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) +$$

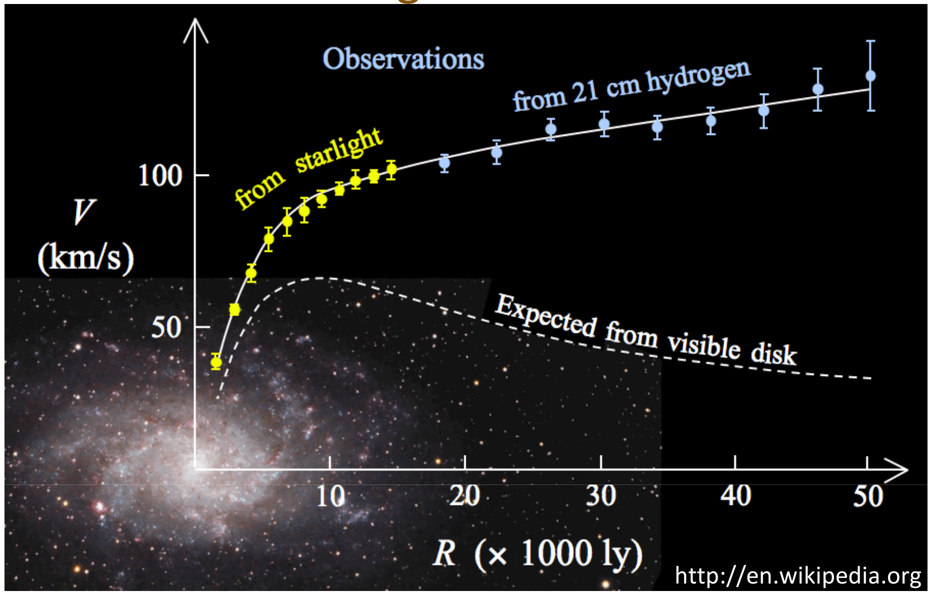
$$igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] -$$

$$\frac{1}{4}g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- +$$

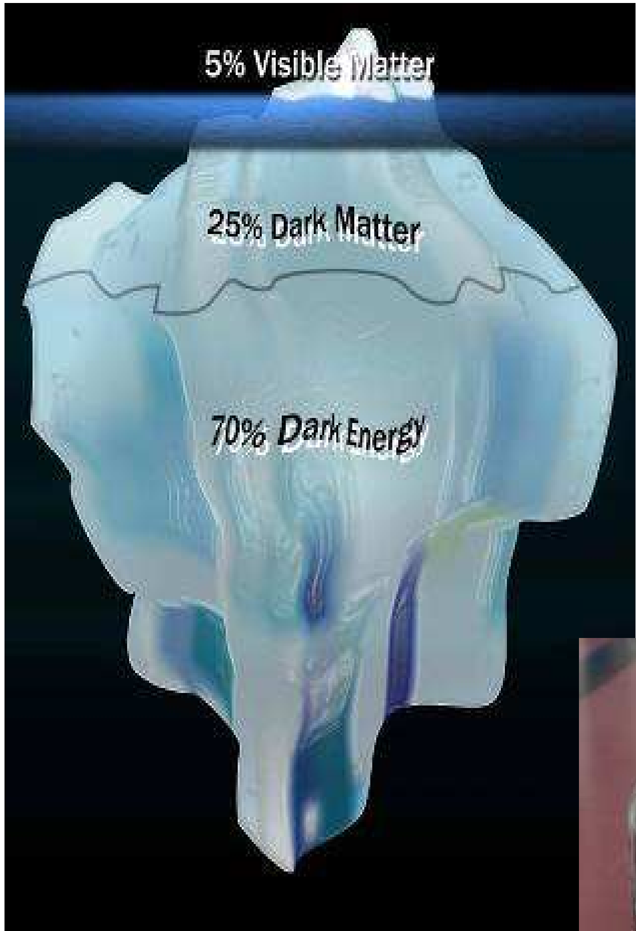
$$W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- +$$

What’s next?

Dark matter holds galaxies?

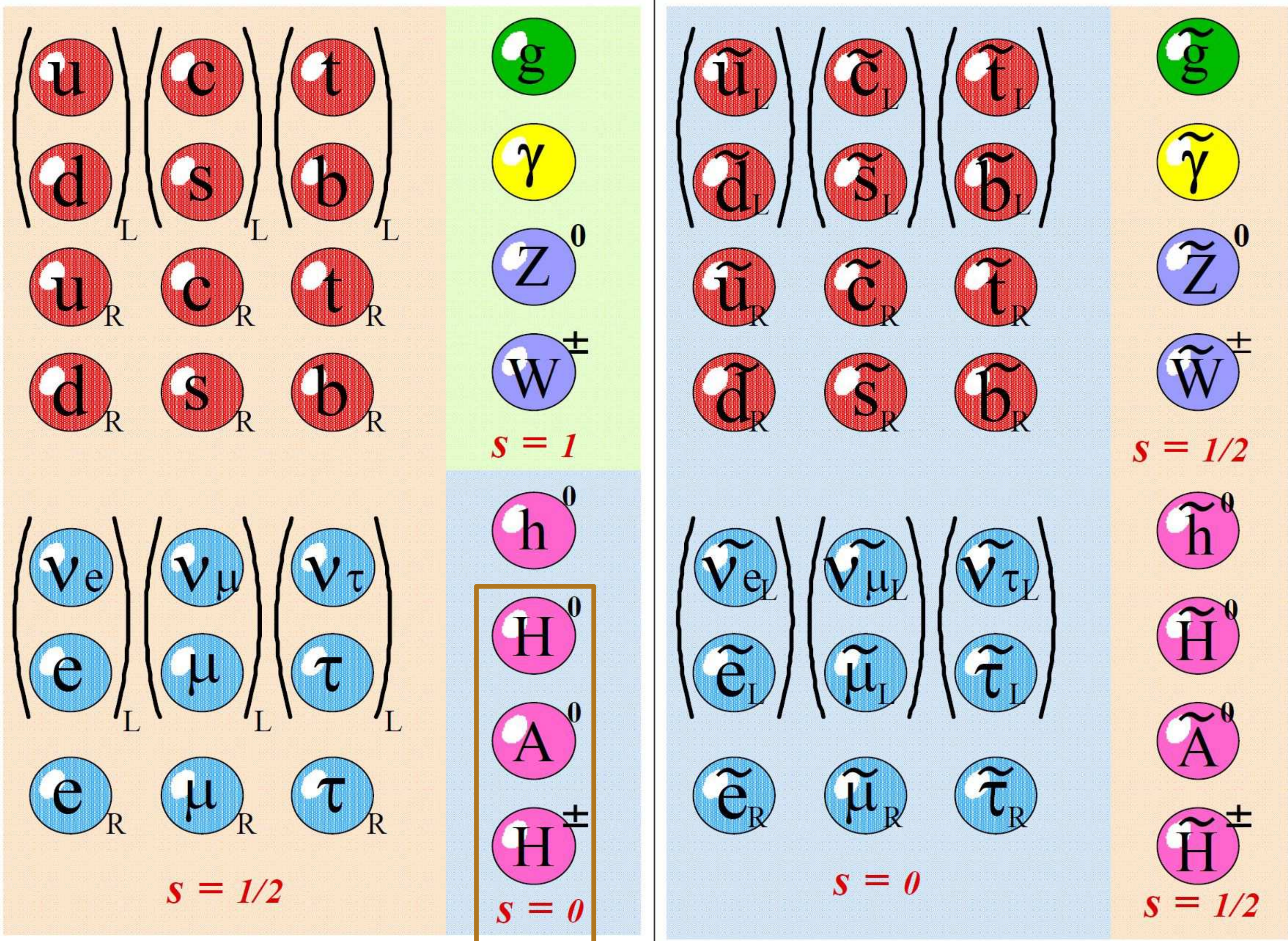


Dark energy pushes Universe apart?



D.Barney (CERN)

Is super-symmetry valid?



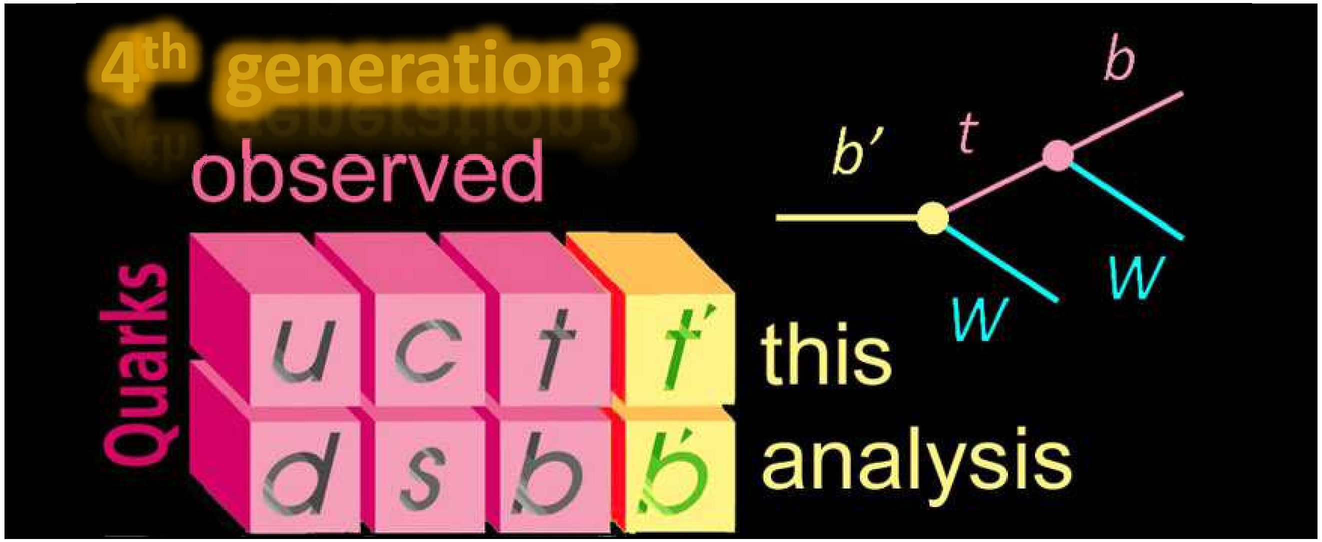
Standard model particles + extras

SUSY particles (MSSM model)

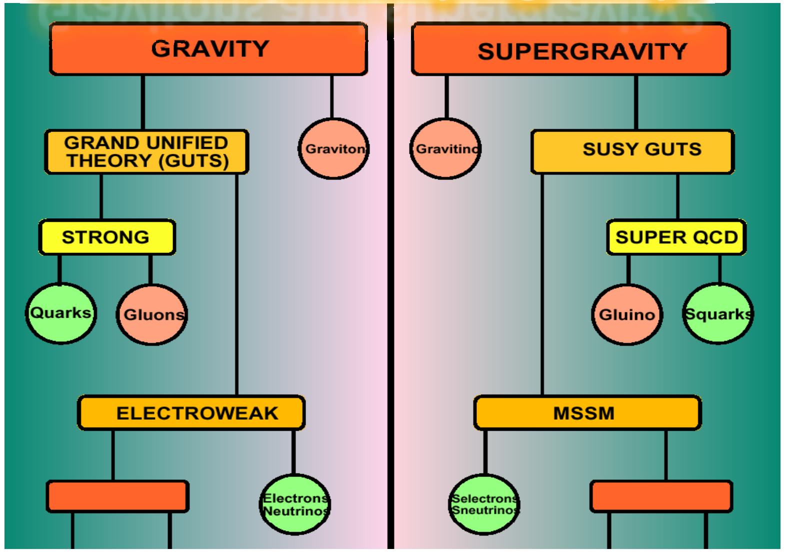
KEK

More particles or dimensions of space?

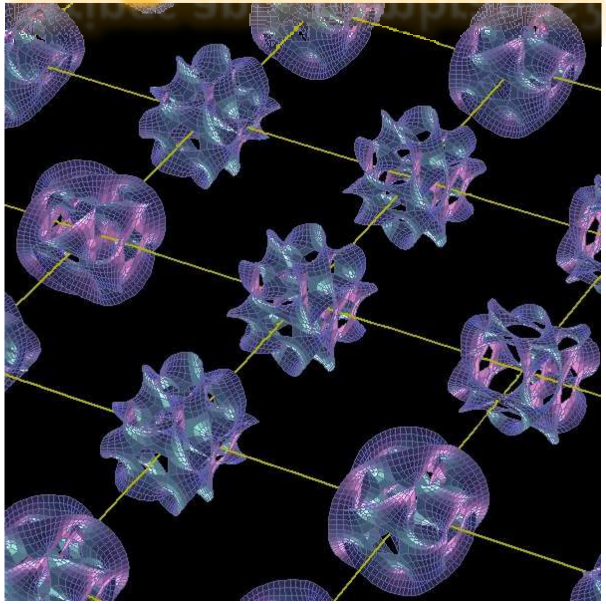
4th generation?



Gravitons and supergravity?

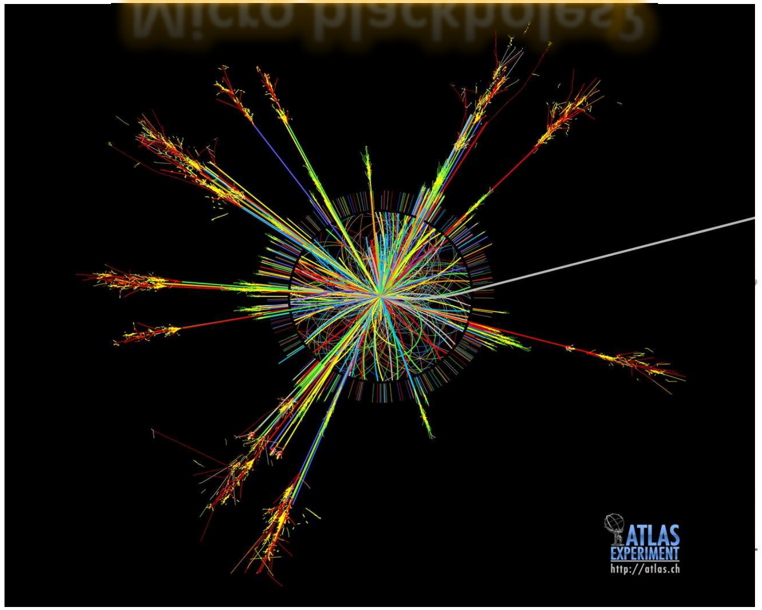


Strings and membranes?

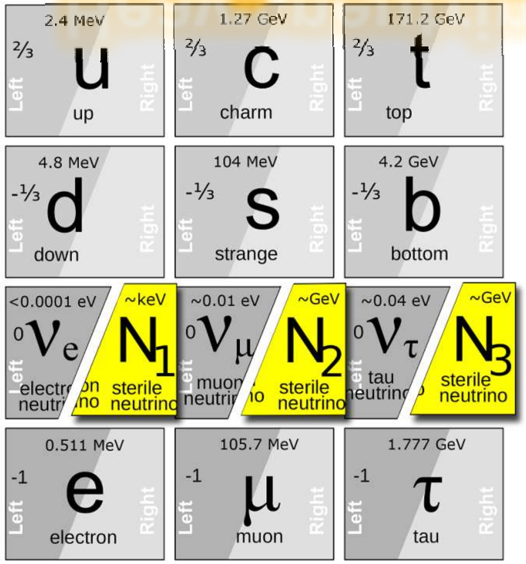


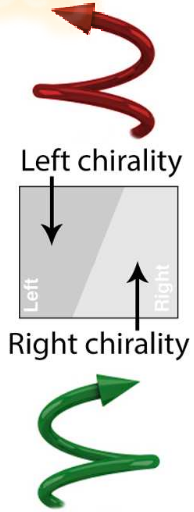
Particlecentral.com

Micro blackholes?



Heavy neutrinos?





A.Boyarsky

Summary

- Discovery of the Higgs boson, the missing piece of the Standard Model, reduced the scope of “probable” theories

- Expect more discoveries at the Large Hadron Collider at CERN and other frontier experiments