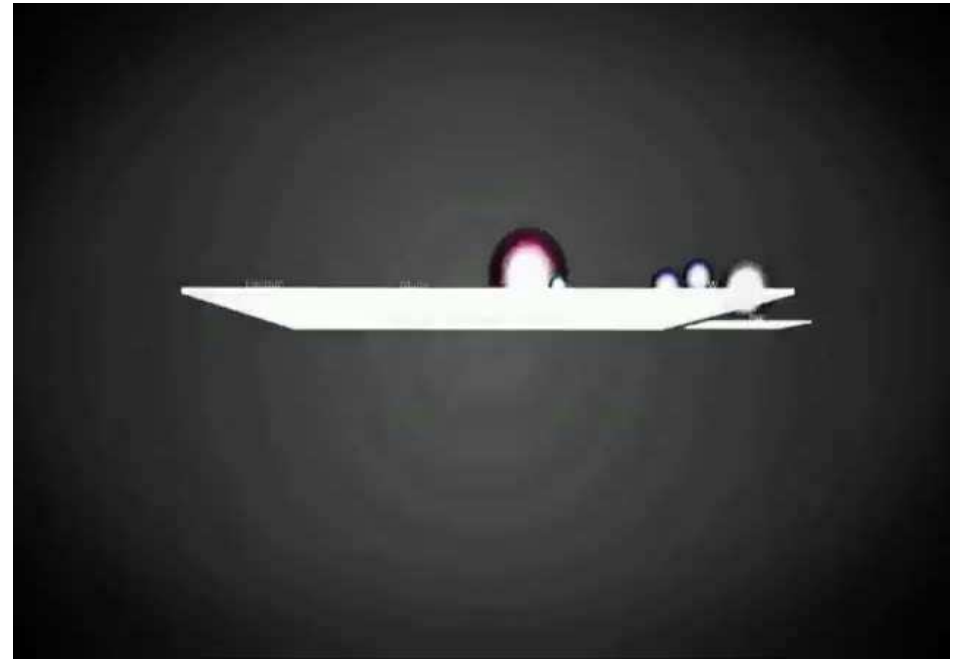


Standard Model

Matter

Force



*What fundamental knowledge
is sought at CERN?*

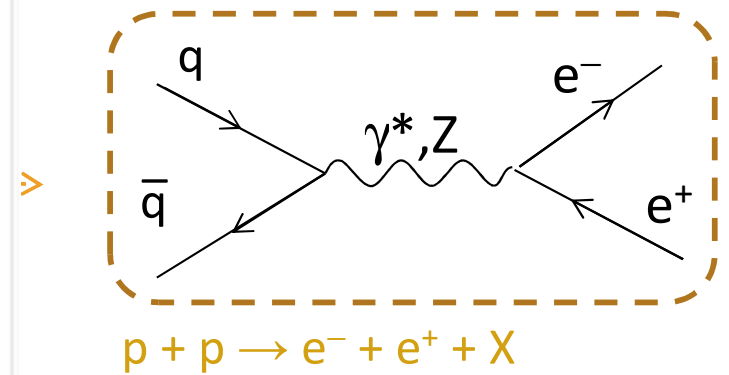
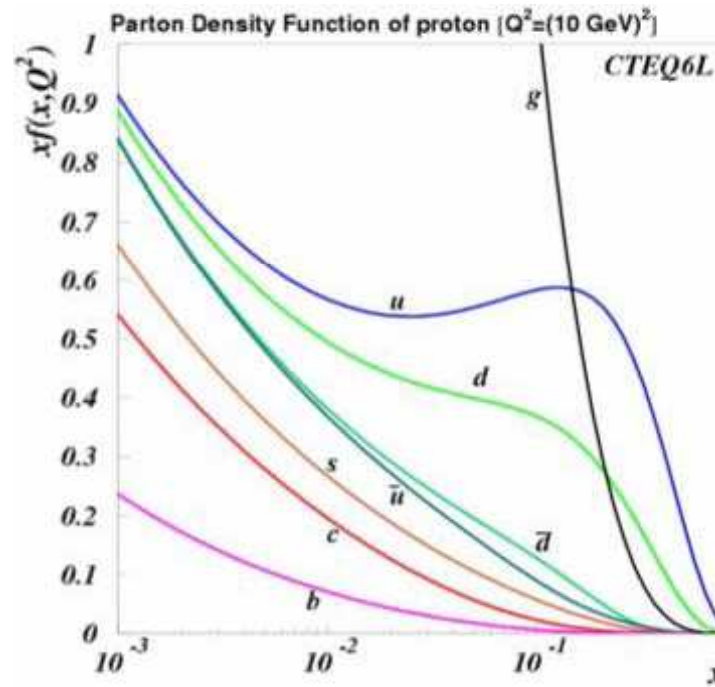
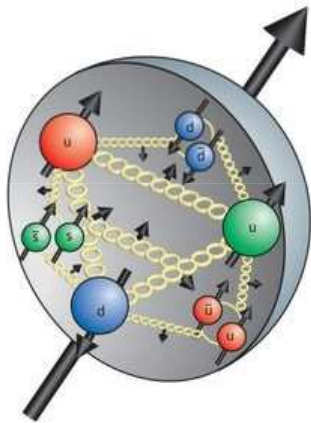
*A. Juodagalvis
Institute of Theoretical Physics and Astronomy,
Vilnius University*



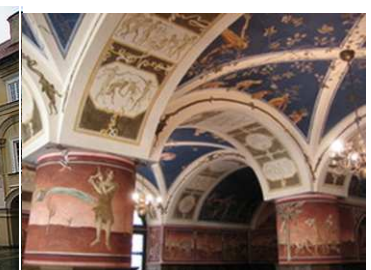
CERN/CMS Computing and Technology
Workshop in Vilnius on December 13, 2016

Drell-Yan process

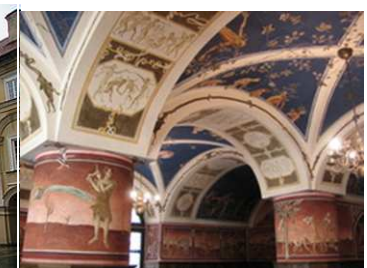
- ▶ The existence of the “quark sea” is proven by the Drell-Yan process, namely, the production of lepton-antilepton pairs in hadron collisions



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



- ▶ 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.



Quarks



up

Lepton



electron

Blueprint:

UUD = proton

UDD = neutron



down

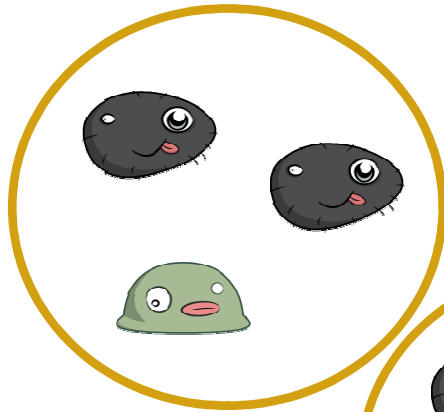
D.Barney (CMS & CERN)



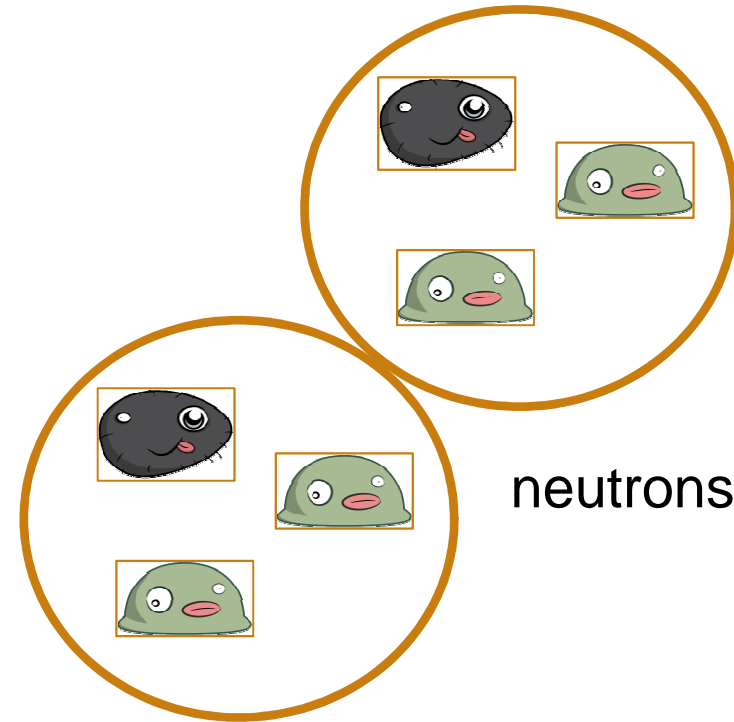
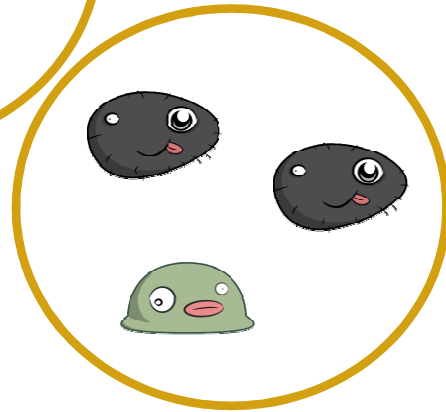
Building an Atom

The helium atom:

electrons



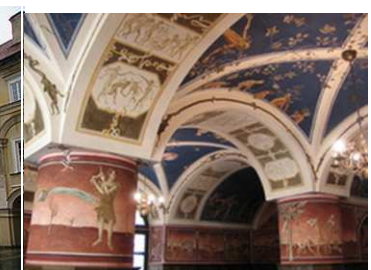
protons



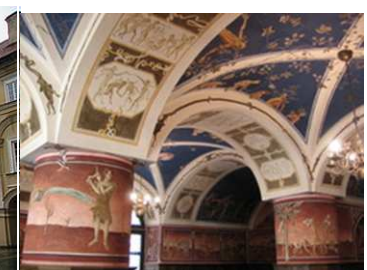
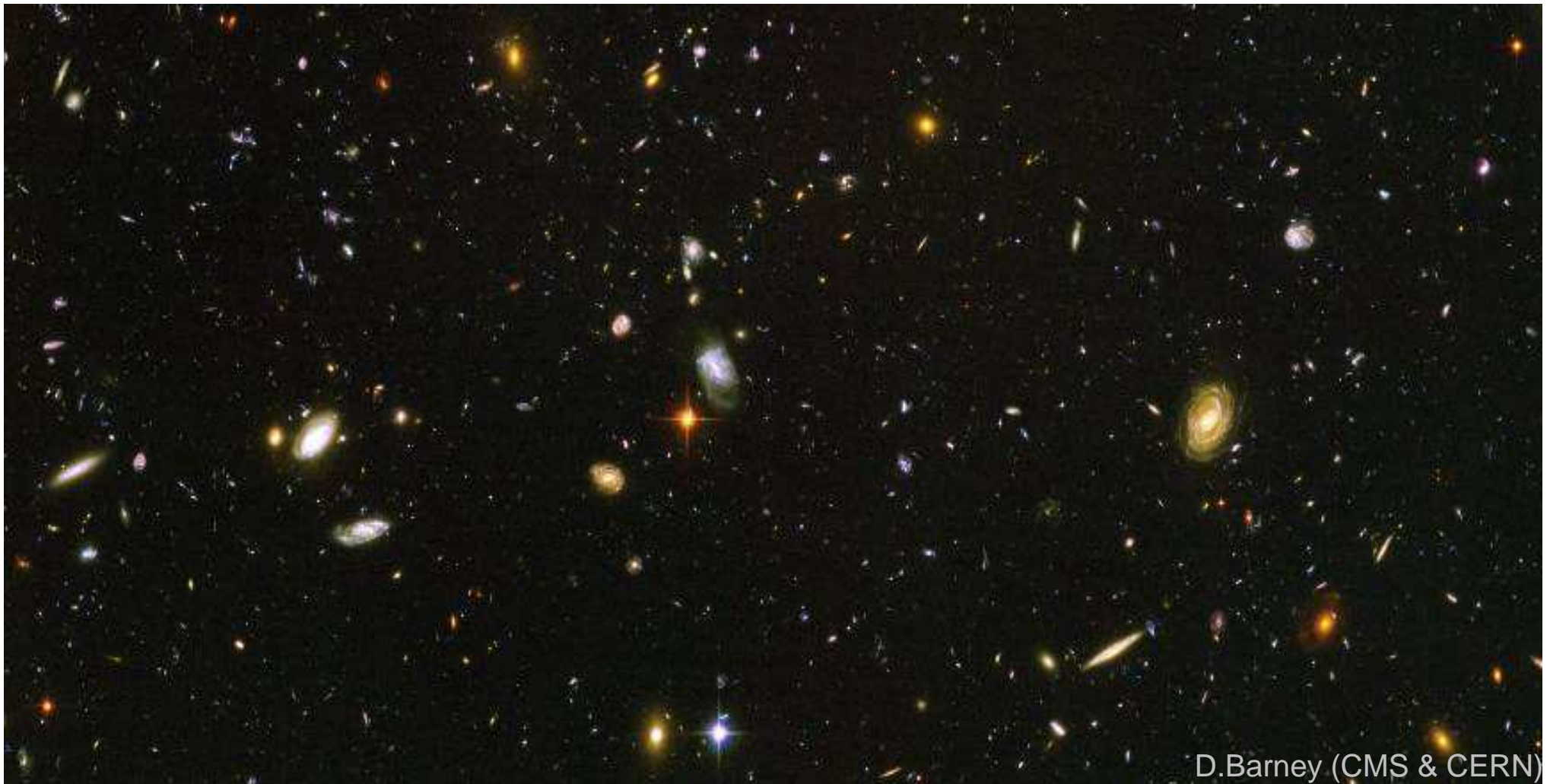
neutrons

Multiply by billions and billions and billions and billions...

D.Barney (CMS & CERN)



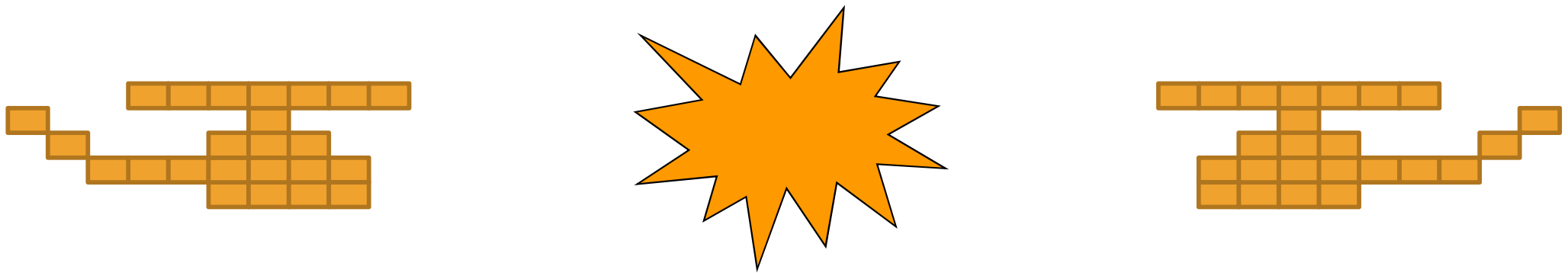
Et voila – the Universe!



A horizontal orange bar is positioned across the middle of the slide. On the left side of this bar, there is a solid orange vertical rectangle. To the right of this rectangle, a white rectangular box with a thin orange border contains the text "This is not a full story...".

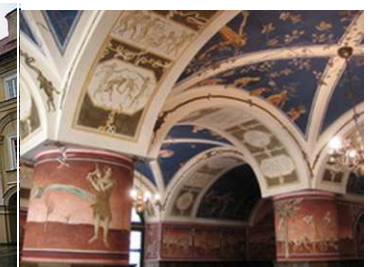
This is not a full story...

What is expected in a collision?

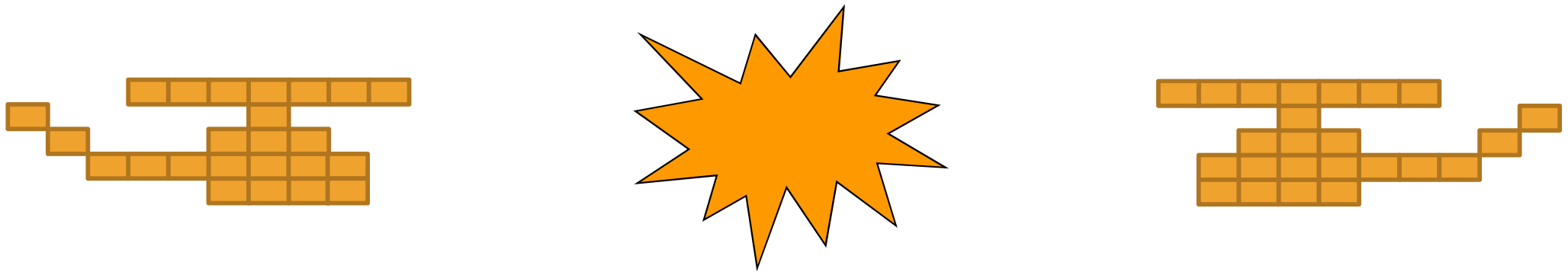


Collision energy

D.Barney (CMS & CERN)

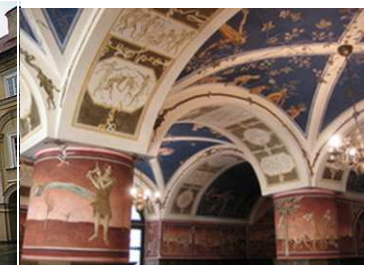


What is expected in a collision?



Collision energy

D.Barney (CMS & CERN)



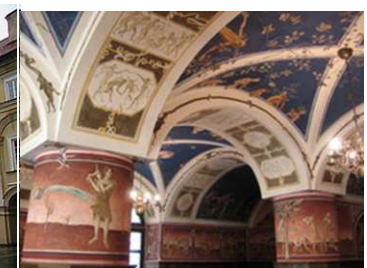
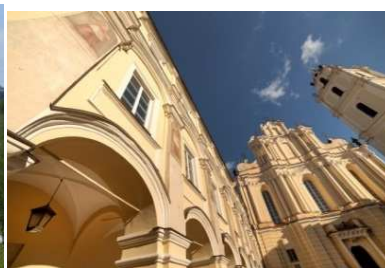
What is expected in a collision *at CERN*?



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

MOVIE

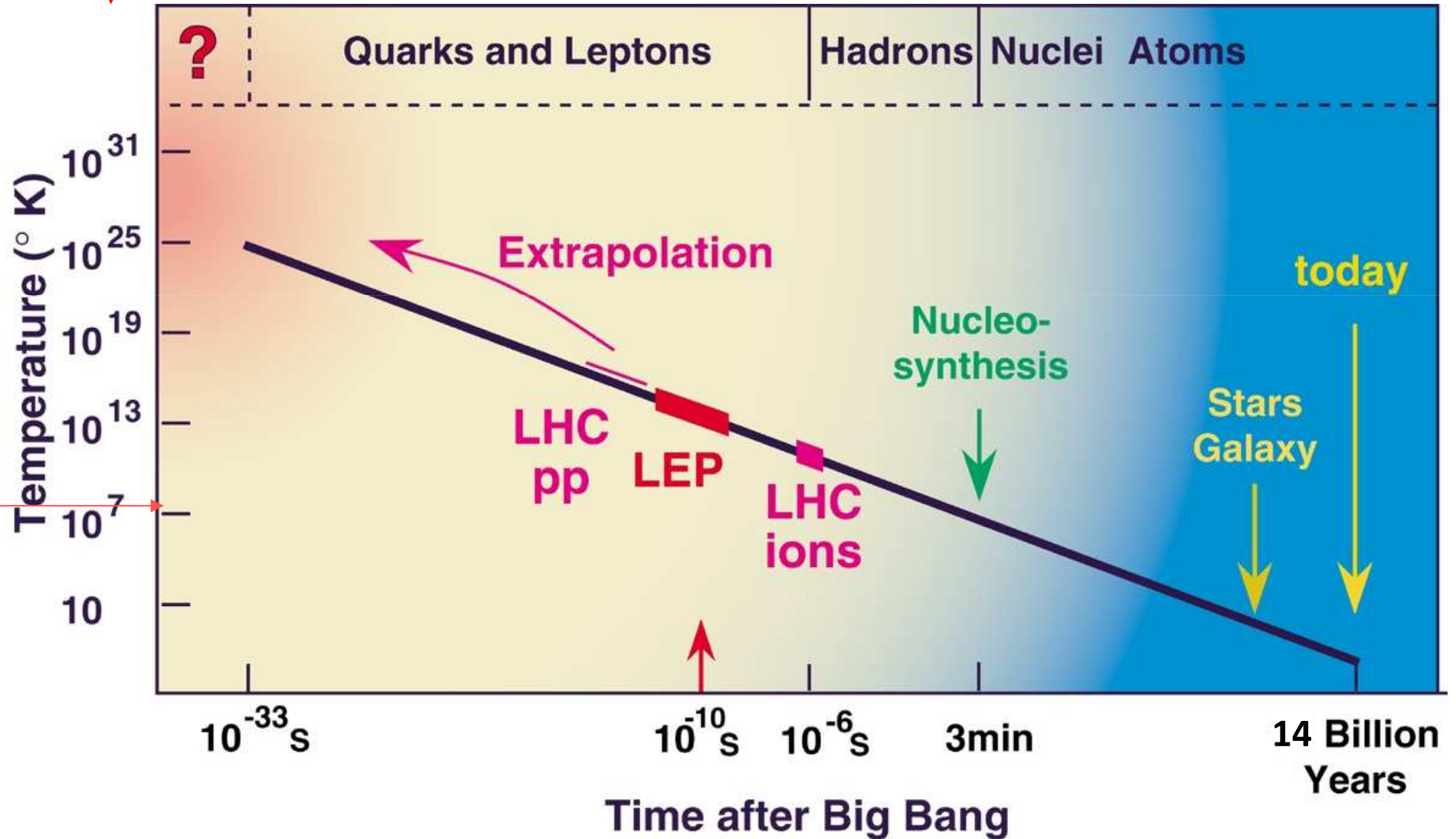


Metaphysics



Quantum Gravity

Electroweak Transition



T_{sun}

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

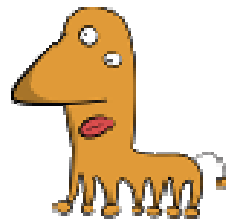
Quarks



up



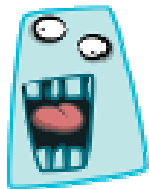
charm



top



down



strange



bottom

Leptons



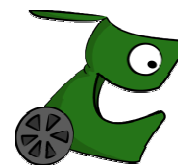
electron



muon



tau



electron neutrino



muon neutrino



tau neutrino

D.Barney (CMS & CERN)



There is also anti-matter....

There is an antiparticle

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



up



electron



down



electron neutrino



anti-up



positron



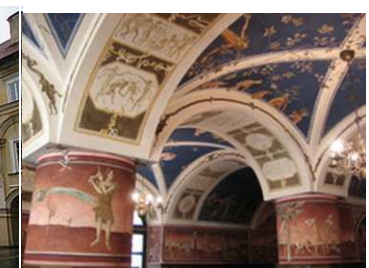
anti-down



Anti-electron neutrino

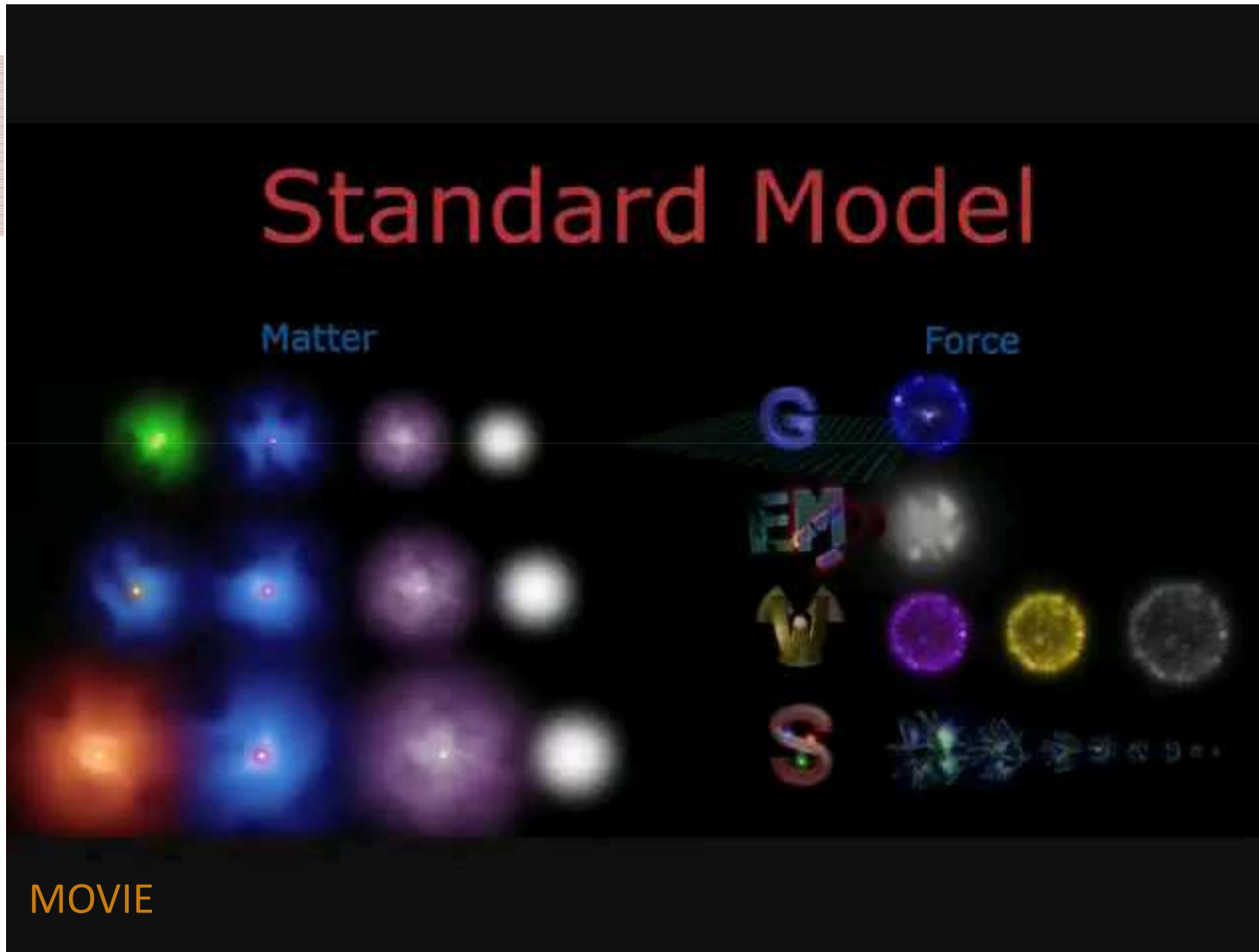
Particles and antiparticles have opposite **electric charge**

D.Barney (CMS & CERN)



Three families of particles

Four fundamental forces



- gravitational
- electromagnetic
- weak
- strong

quarks

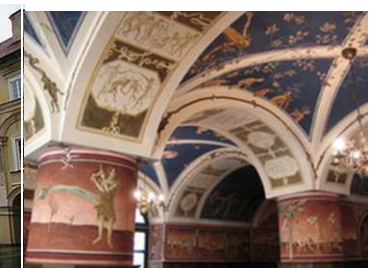
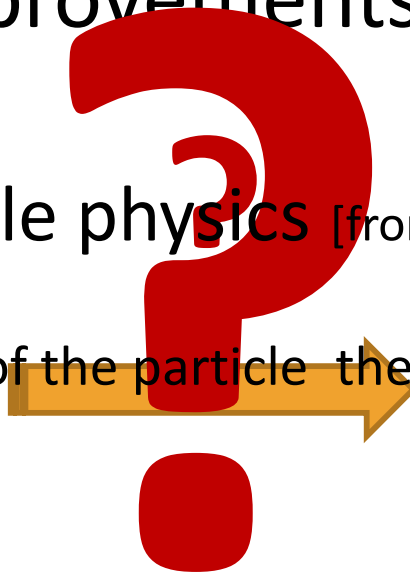
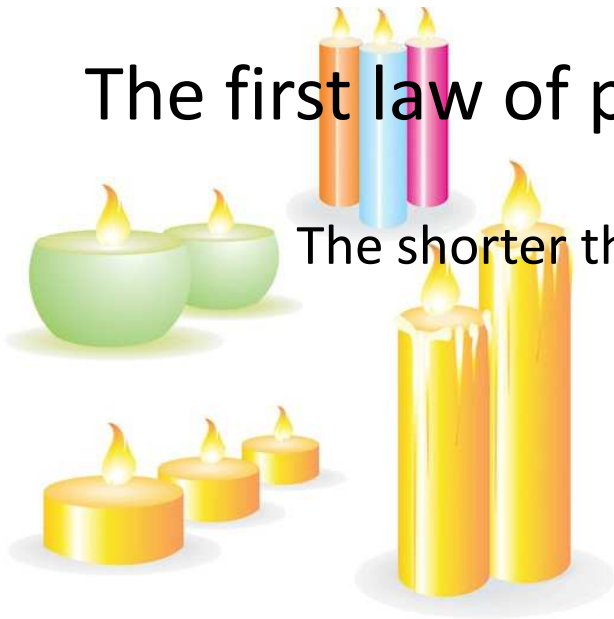
| leptons

force carriers

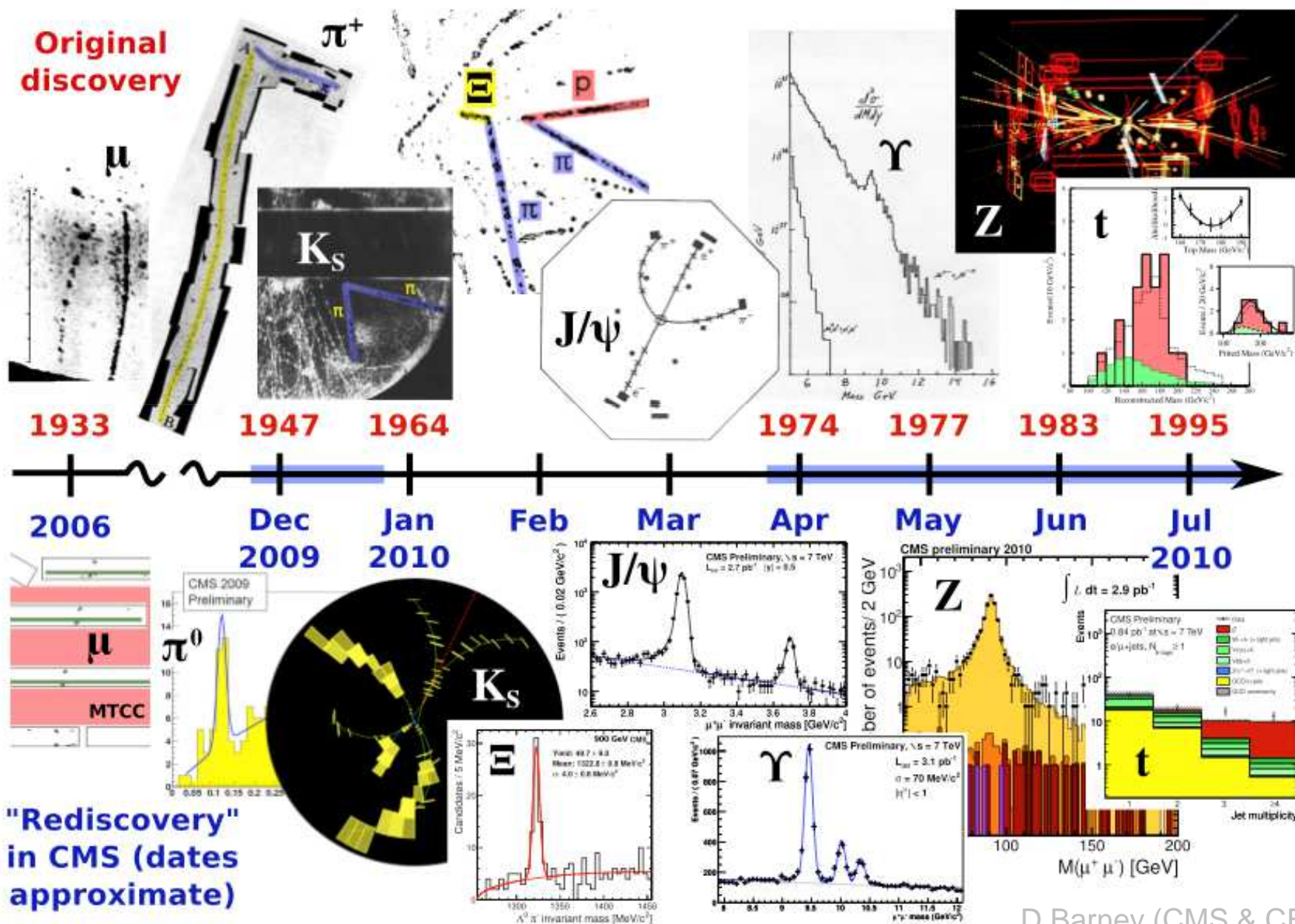
How many improvements are needed?

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

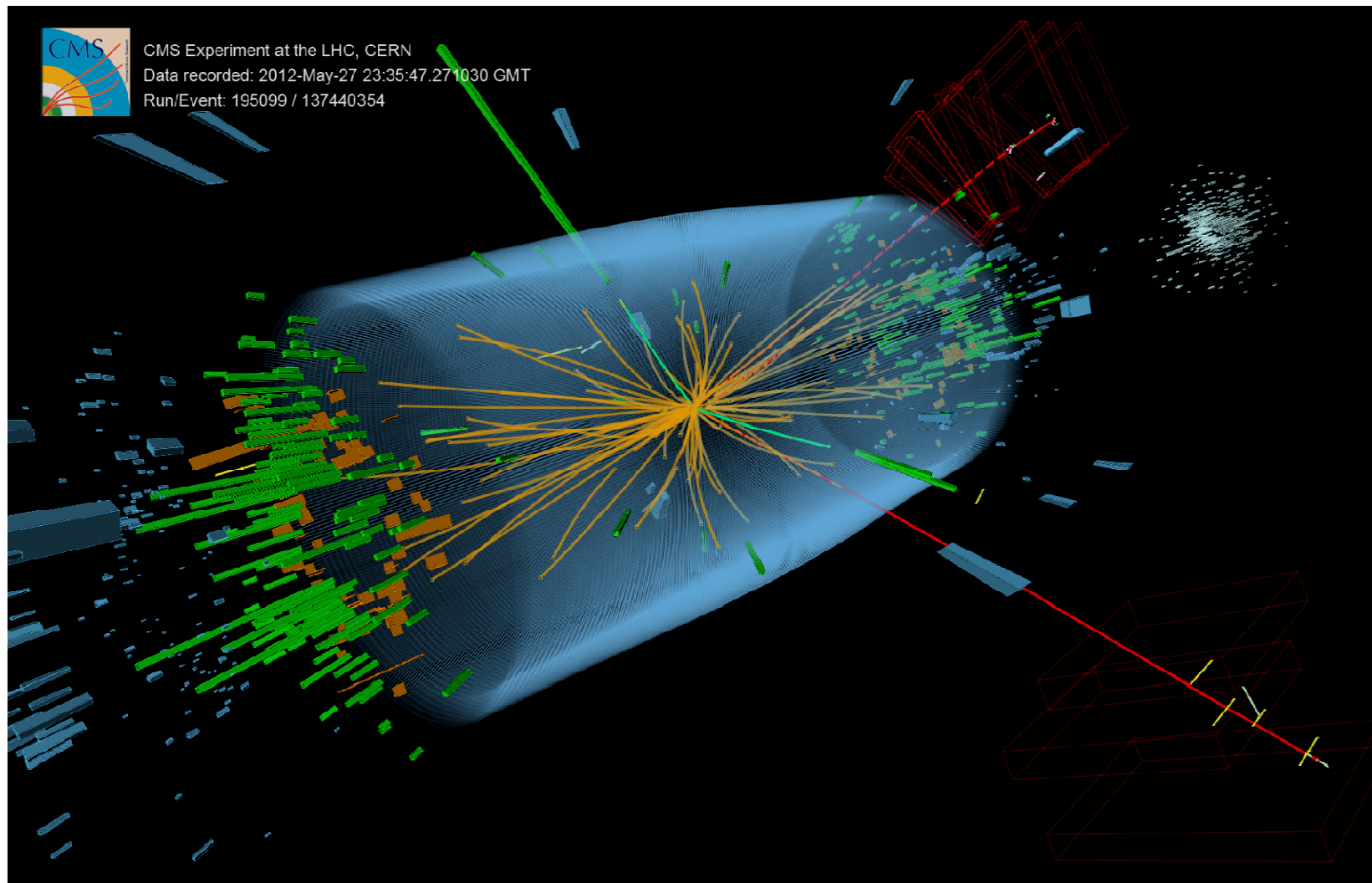
The shorter the life of the particle → the more it costs to produce.



Re-discovery in CMS



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”

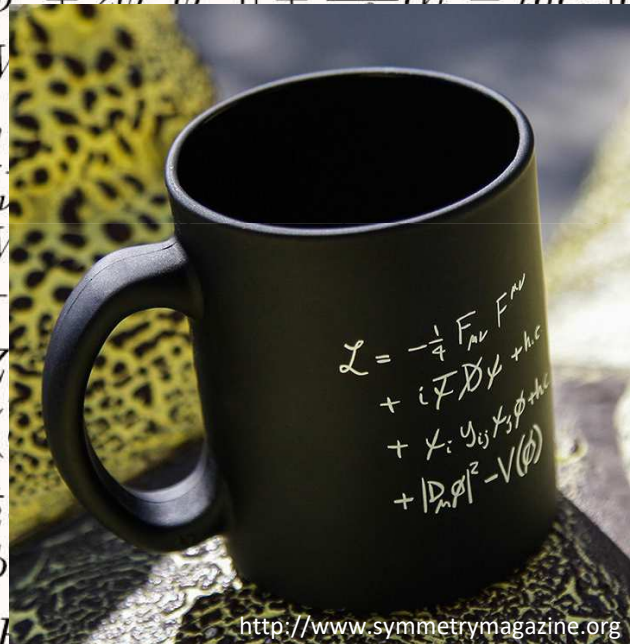


F.Englert and P.W.Higgs

	<p>mass → =2.3 MeV/c²</p> <p>charge → 2/3</p> <p>spin → 1/2</p> <p>u</p> <p>up</p>	<p>mass → =1.275 GeV/c²</p> <p>charge → 2/3</p> <p>spin → 1/2</p> <p>c</p> <p>charm</p>	<p>mass → =173.07 GeV/c²</p> <p>charge → 2/3</p> <p>spin → 1/2</p> <p>t</p> <p>top</p>
QUARKS	<p>mass → =4.5 MeV/c²</p> <p>charge → -1/3</p> <p>spin → 1/2</p> <p>d</p> <p>down</p>	<p>mass → =95 MeV/c²</p> <p>charge → -1/3</p> <p>spin → 1/2</p> <p>s</p> <p>strange</p>	<p>mass → =4.18 GeV/c²</p> <p>charge → -1/3</p> <p>spin → 1/2</p> <p>b</p> <p>bottom</p>
	<p>mass → 0.511 MeV/c²</p> <p>charge → -1</p> <p>spin → 1/2</p> <p>e</p> <p>electron</p>	<p>mass → 106.7 MeV/c²</p> <p>charge → -1</p> <p>spin → 1/2</p> <p>μ</p> <p>muon</p>	<p>mass → 1.777 GeV/c²</p> <p>charge → -1</p> <p>spin → 1/2</p> <p>τ</p> <p>tau</p>
	<p>mass → < 2.2 eV/c²</p> <p>charge → 0</p> <p>spin → 1/2</p> <p>ν_e</p> <p>electron neutrino</p>	<p>mass → 0.17 MeV/c²</p> <p>charge → 0</p> <p>spin → 1/2</p> <p>ν_μ</p> <p>muon neutrino</p>	<p>mass → 16.5 MeV/c²</p> <p>charge → 0</p> <p>spin → 1/2</p> <p>ν_τ</p> <p>tau neutrino</p>

MissMJ, <http://en.wikipedia.org>

$$\begin{aligned}
 & -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \\
 & \frac{1}{2}ig_s^2 (\bar{q}_i^\sigma \gamma^\mu q_j^\sigma) g_\mu^a + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - \\
 & M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2} M^2 Z_\mu^0 Z_\mu^0 - \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. \\
 & \left. \frac{2M}{a} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{a} \alpha_\nu - igc [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ \partial_\nu W_\mu^- - \\
 & \nu (W_\mu^+ \partial_\nu W_\mu^- - \\
 & + W_\mu^- W_\nu^+ W_\nu^- + \\
 & \nu W_\mu^+ W_\nu^-) + \\
 & Z_\nu^0 (W_\mu^+ W_\nu^- - \\
 & - 2H \phi^+ \phi^-] - \\
 & \phi^- + 2(\phi^0)^2 H^2] - \\
 & - \phi^- \partial_\mu \phi^0) - \\
 & - W_\mu^- (H \partial_\mu \phi^+ - \\
 & W_\mu^+ \phi^- - W_\mu^- \phi^+) + \\
 & ig s_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
 & ig s_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_\mu^0 Z_\mu^0 [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_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z_\mu^0 H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 s_w (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- -
 \end{aligned}$$

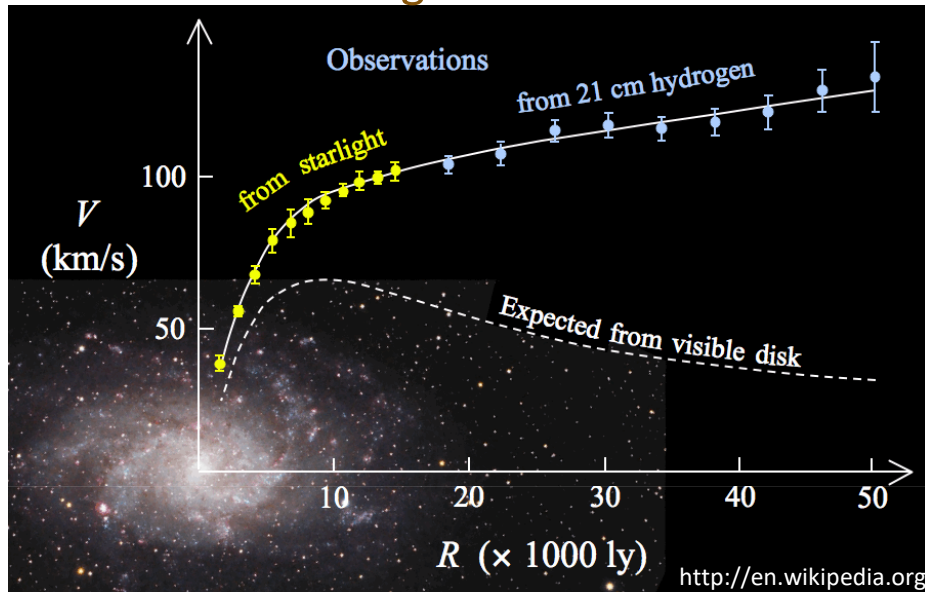


<http://www.symmetrymagazine.org>



What's next?

Dark matter holds galaxies?

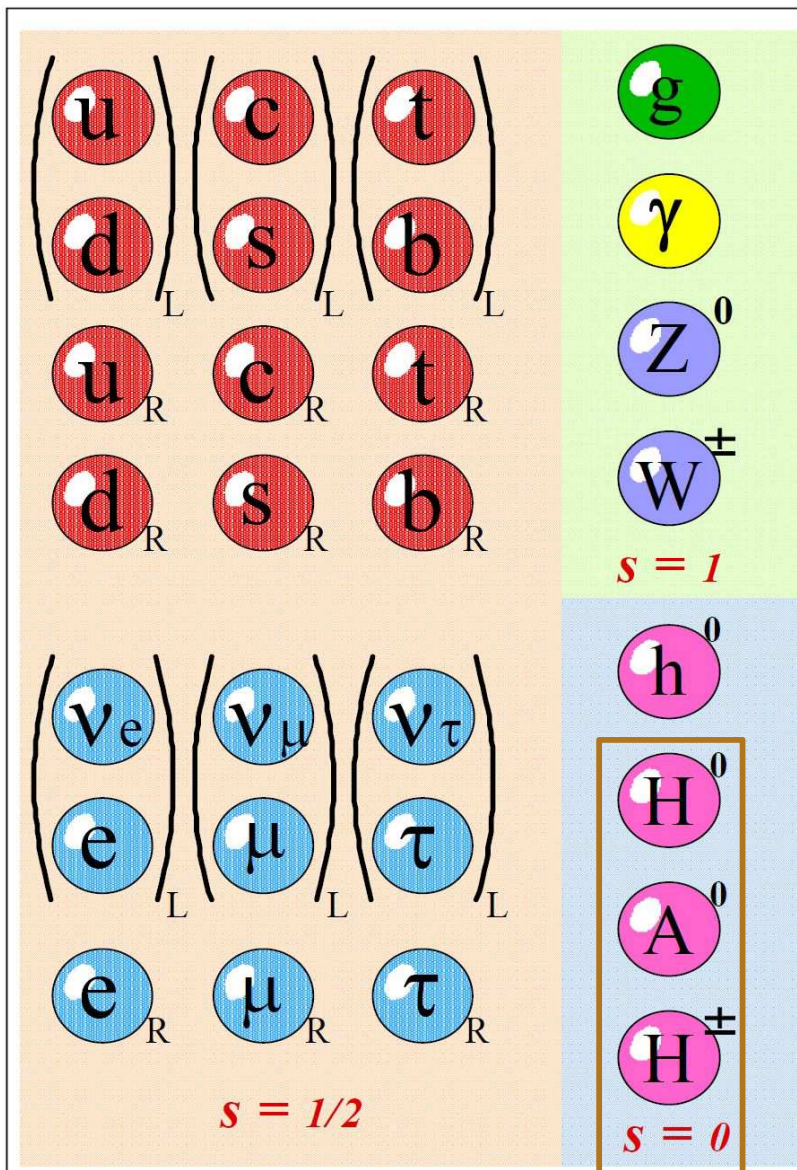
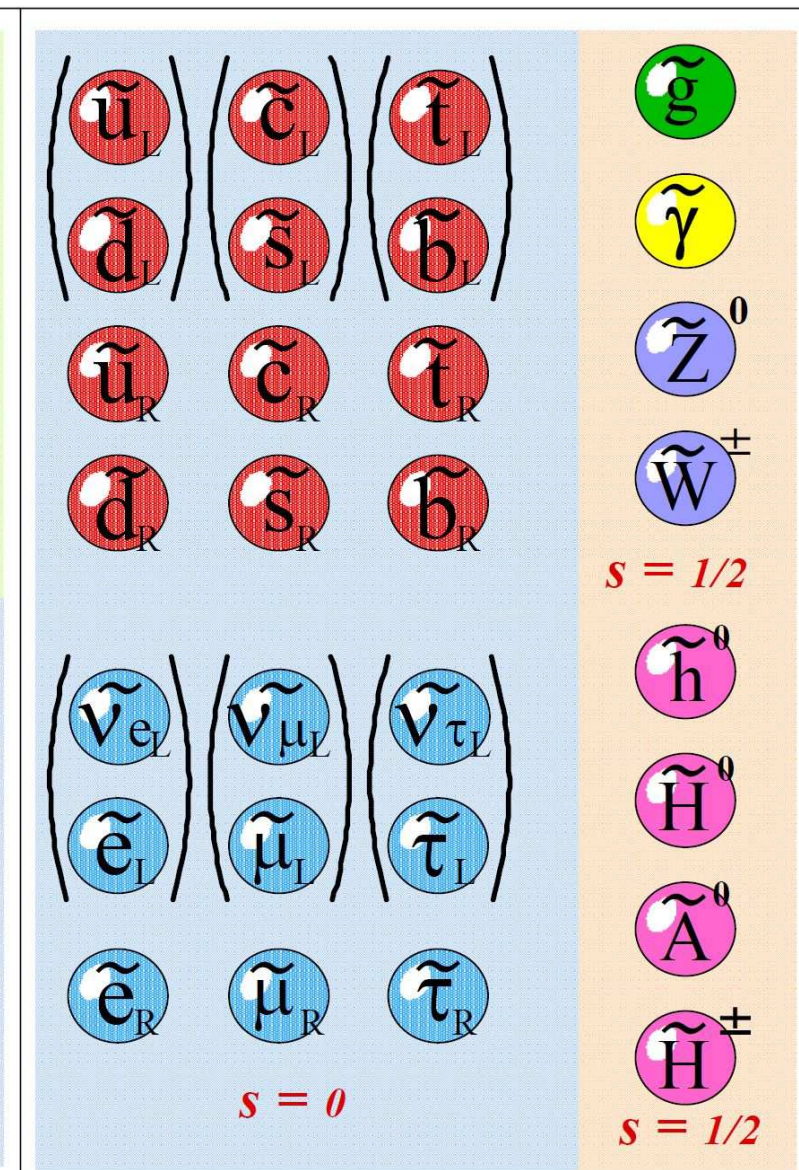


D.Barney (CERN)

Dark energy pushes Universe apart?



Is super-symmetry valid?

 <p>Standard model particles + extras</p>	 <p>SUSY particles (MSSM model)</p>
<p> $\begin{pmatrix} u \\ d \end{pmatrix}_L$ $\begin{pmatrix} c \\ s \end{pmatrix}_L$ $\begin{pmatrix} t \\ b \end{pmatrix}_L$ </p> <p> u_R c_R t_R </p> <p> d_R s_R b_R </p> <p> $s = 1$ </p> <p> $\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L$ $\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L$ $\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$ </p> <p> e_R μ_R τ_R </p> <p> $s = 1/2$ </p> <p> g γ Z^0 W^\pm h^0 H^0 A^0 H^\pm $s = 0$ </p>	<p> $\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$ $\begin{pmatrix} \tilde{c}_L \\ \tilde{s}_L \end{pmatrix}$ $\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$ </p> <p> \tilde{u}_R \tilde{c}_R \tilde{t}_R </p> <p> \tilde{d}_R \tilde{s}_R \tilde{b}_R </p> <p> $s = 1/2$ </p> <p> $\begin{pmatrix} \tilde{\nu}_e \\ \tilde{e}_L \end{pmatrix}$ $\begin{pmatrix} \tilde{\nu}_\mu \\ \tilde{\mu}_L \end{pmatrix}$ $\begin{pmatrix} \tilde{\nu}_\tau \\ \tilde{\tau}_L \end{pmatrix}$ </p> <p> \tilde{e}_R $\tilde{\mu}_R$ $\tilde{\tau}_R$ </p> <p> $s = 0$ </p> <p> \tilde{g} $\tilde{\gamma}$ \tilde{Z}^0 \tilde{W}^\pm \tilde{h}^0 \tilde{H}^0 \tilde{A}^0 \tilde{H}^\pm $s = 1/2$ </p>
<p>Standard model particles + extras</p>	<p>SUSY particles (MSSM model)</p>

More particles or dimensions of space?

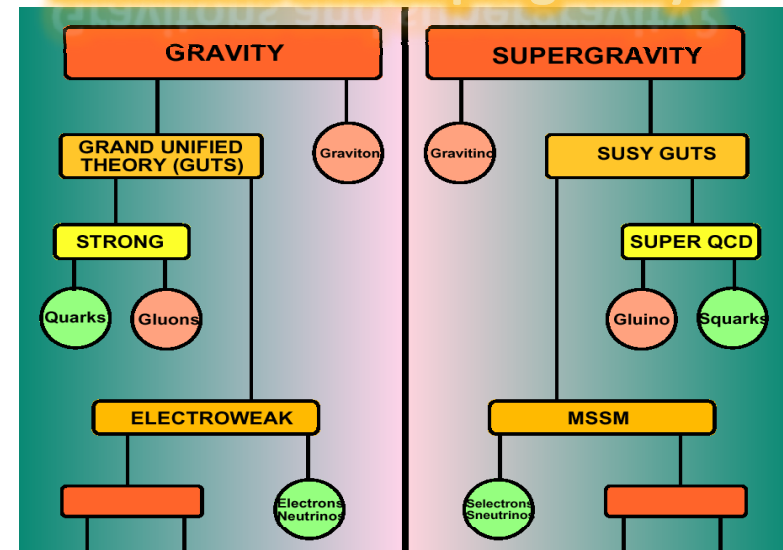
Gravitons and supergravity?

4th generation?
observed

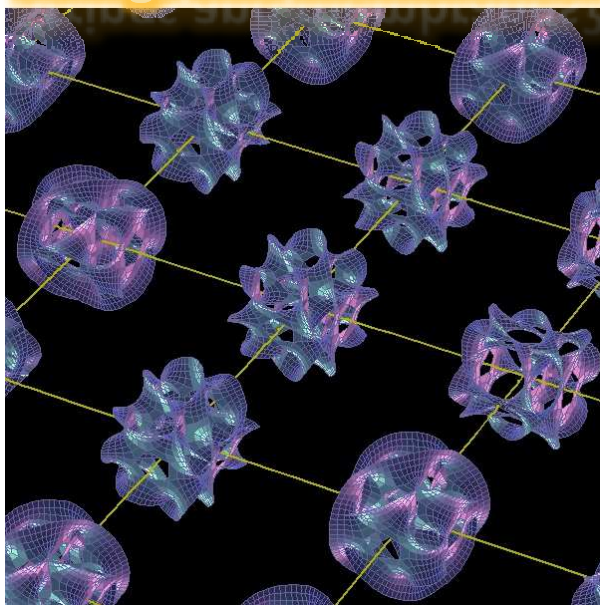
Quarks

u	c	t	t'
d	s	b	b'

this analysis

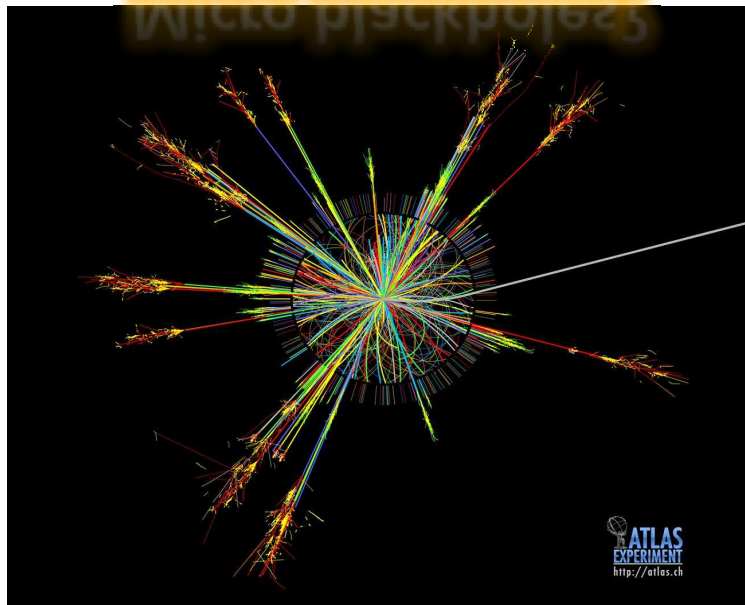


Strings and membranes?



Particlecentral.com

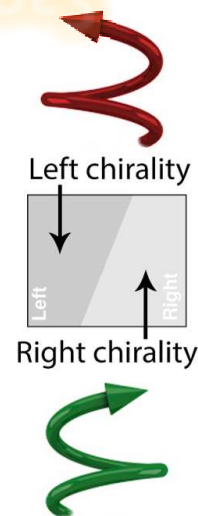
Micro blackholes?



Heavy neutrinos?

2.4 MeV $\frac{2}{3}$ Left u up Right	1.27 GeV $\frac{2}{3}$ Left c charm Right	171.2 GeV $\frac{2}{3}$ Left t top Right
4.8 MeV $-\frac{1}{3}$ Left d down Right	104 MeV $-\frac{1}{3}$ Left s strange Right	4.2 GeV $-\frac{1}{3}$ Left b bottom Right
<0.0001 eV 0 Left ν_e electron neutrino Right	~keV N_1 sterile neutrino Right	~0.01 eV 0 Left ν_μ muon neutrino Right
~GeV N_2 sterile neutrino Right	~0.04 eV 0 Left ν_τ tau neutrino Right	~GeV N_3 sterile neutrino Right
0.511 MeV -1 Left e electron Right	105.7 MeV -1 Left μ muon Right	1.777 GeV -1 Left τ tau Right

A.Boyarsky



- ▶ 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

