

Introduction to Particle Physics

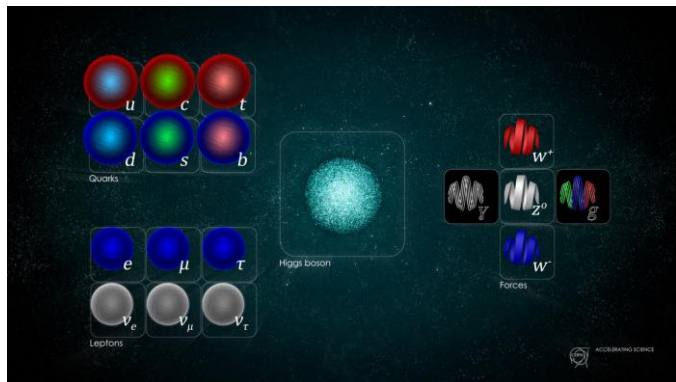
SWEDISH PHYSICS TEACHERS 2023

Handout 3

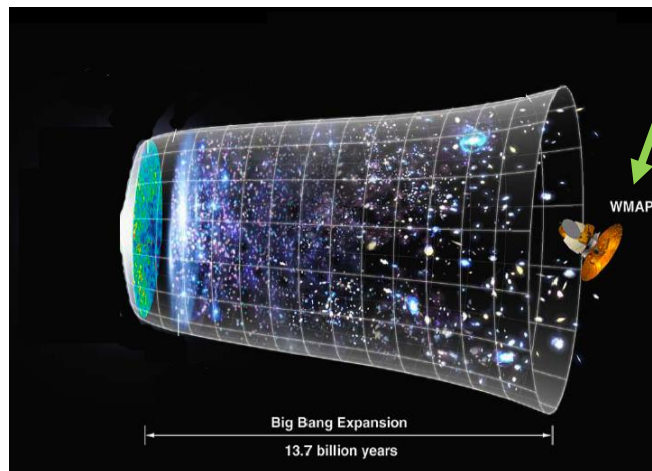
Beyond the SM

- Limits of the SM
- Grand unified theories (GUT) (speculative)
- Theories of Everything (ToE) (Merely speculative !)

Standard Model + General Relativity = Universe ?



+



Wilkinson Microwave Anisotropy Probe

WMAP

=



Not yet !

- dark matter
- dark energy

What the SM doesn't explain

Dark matter: galaxy rotate too fast! It exists some extra matter not visible. It accounts for 23% of the total mass-energy. Which type of matter?

Dark energy: the universe expansion is accelerating. As a consequence, there is injection of energy. 73 % of total energy. What is its origin?

We are in the 0.4% of the observable 4% mass-energy!

SM doesn't incorporate the neutrino oscillation (then neutrino mass);

Origin of mass;

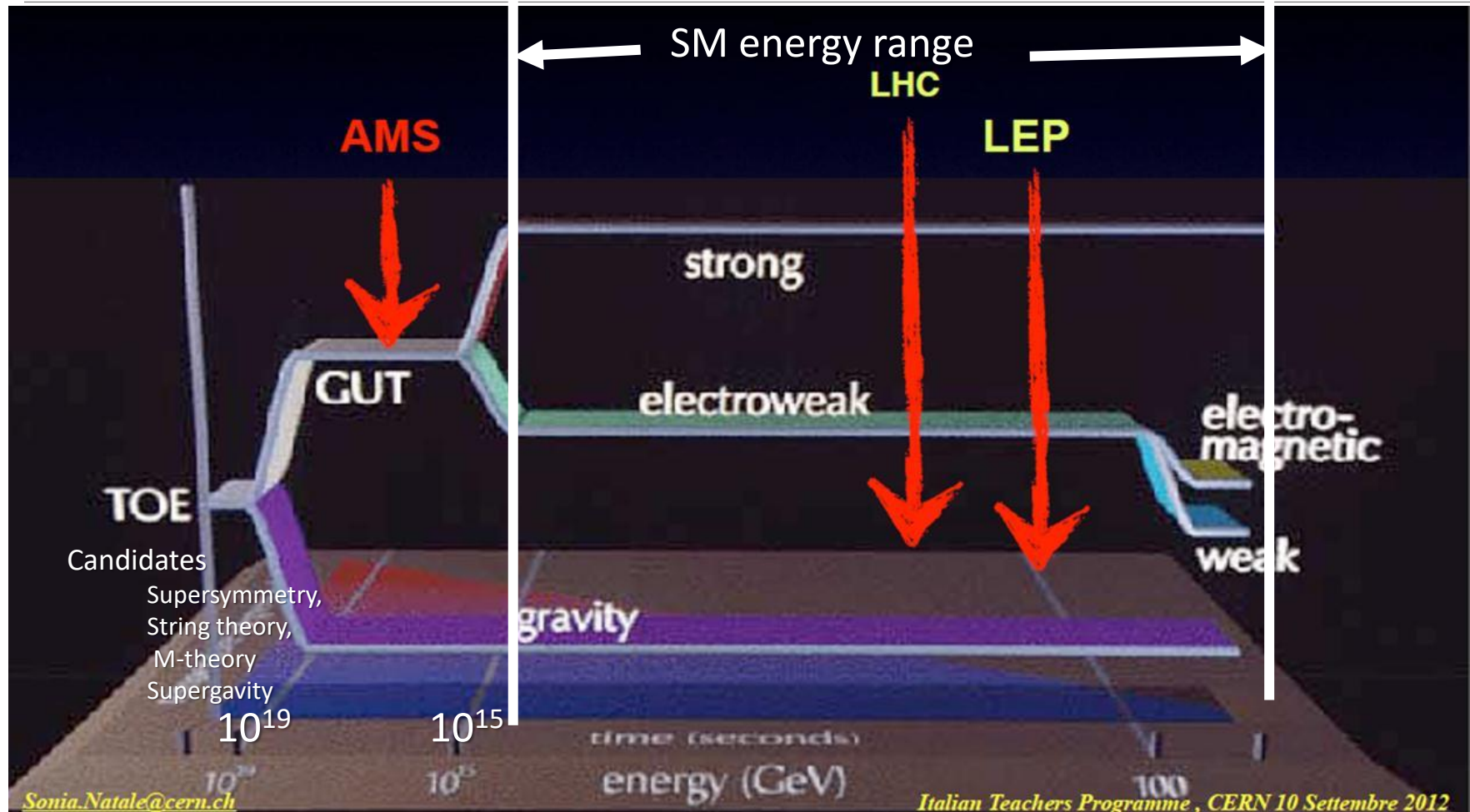
matter-antimatter asymmetry;;

....

Grand Unified Theories and Theory of Everything

A scientific challenge ...and maybe a romantic dream,
for a unified description of the Universe

Energy scale for GUT and ToE



GUT what?

Grand Unified Theories !

Theories with the objective of unifying the gauge interactions (EW and QCD) into one universal interaction;

The unification energy is expected at around 10^{14} GeV! LHC energy 10^4 GeV. So, no new physics in the 10 decades of energy increase (if true, bad news for the FCC program!...but H boson precision measurement still possible..and you never know...)

A GUT candidate is labelled SU(5)

Theory of Everything

Theory with the objective to unify the Electroweak and Strong interactions with the gravity!

Candidates:

1. Composite models
2. Supersymmetry (SUSY)
3. Kaluza-Klein theories
4. String models
5. M-theories

(1) Composite structure

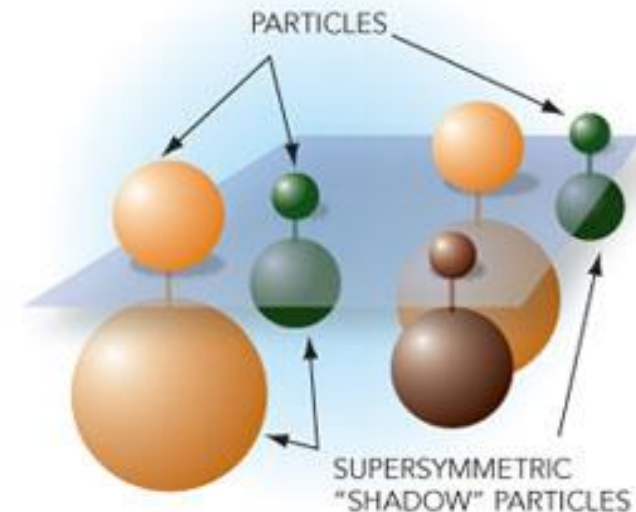
Electron and quark are assumed as composite structure;

So far no evidence from the cross section trend that assumes the fermions as point-like objects!!

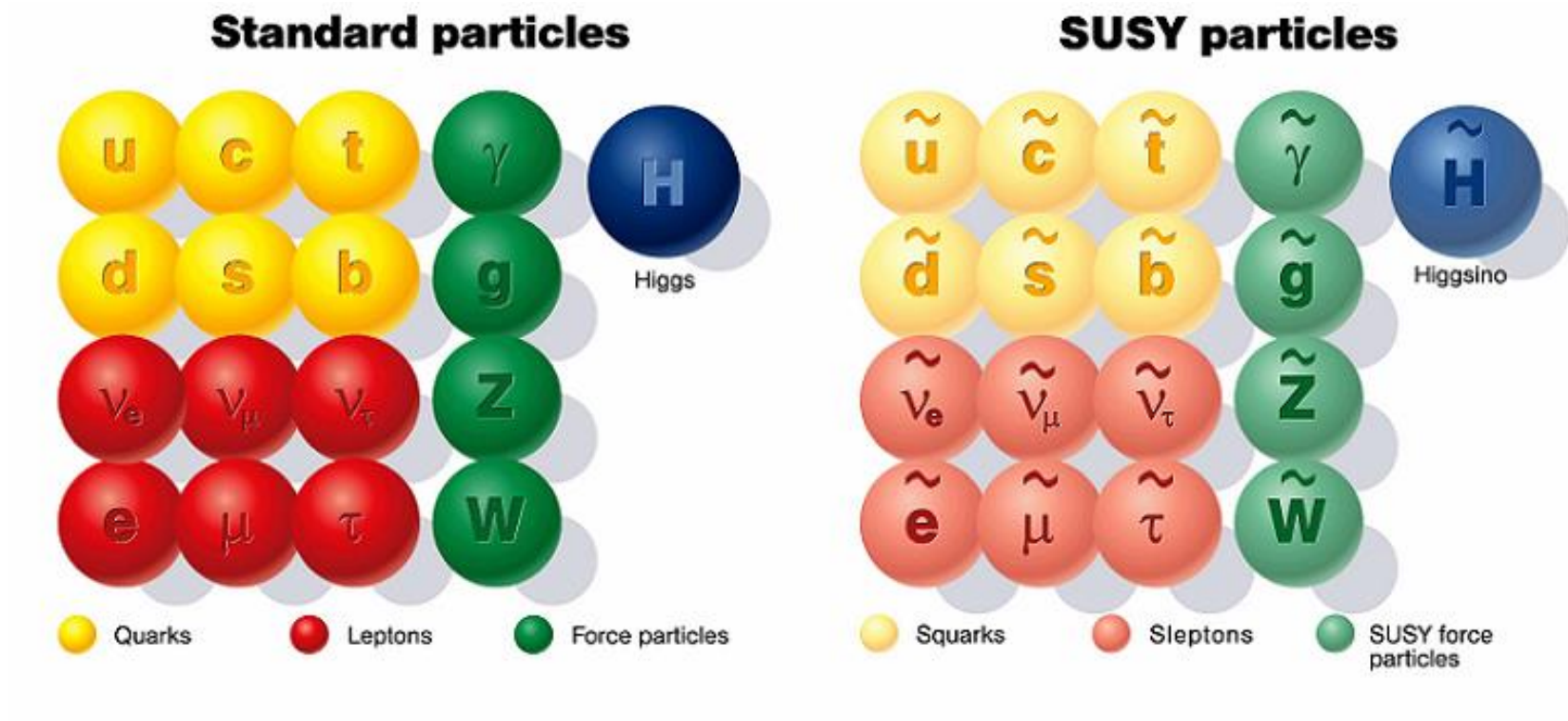
(2) SUPERSYMMETRY (SUSY)

- SUSY can include the Gravity;
- A connection between fermion fields (spin 1/2) and boson fields (spin 1) exists;
- We know that fermions (quarks and leptons) interact through the exchange of gauge bosons (gluons, photon, W^\pm and Z^0);
- “SUPERSYMMETRY” predicts a complete symmetry between particles of matter and Interaction carriers :

Spin ½ (fermions)	Spin 0, Spin 1 (bosons)
electron	selectron (S=0)
quark	squark (S=0)
photino	photon (S=1)
gluino	gluon (S=1)
gaugino (Wino, Zino)	W, Z (S=1)



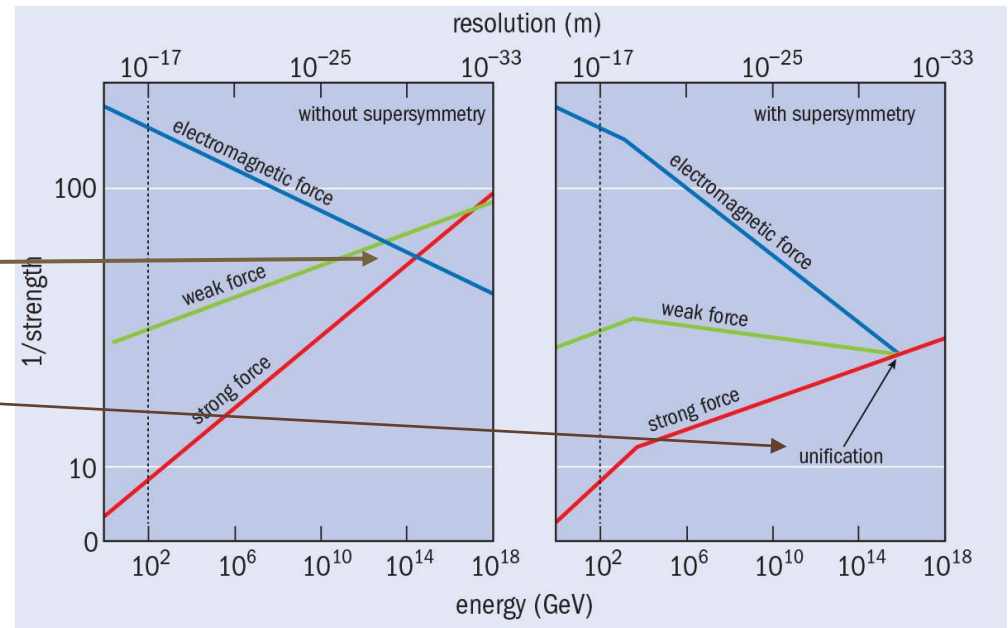
SUSY at one glance



Why 3 interactions?

Forces “run” with energy and don’t agree at high energy

SUSY can modify their evolution to join up → unification @ 10^{14} GeV



SUSY could explain the cosmological matter-antimatter asymmetry;

Lightest supersymmetric particle = dark matter ;

Unfortunately, so far, no evidence of supersymmetric particles neither in ATLAS nor in CMS search!!

Supersymmetric BEH bosons

If the supersymmetry exist then 5 Higgs bosons should exist (three neutral and two electrically charged)

In this case the BEH boson discovered at LHC, could be one out of the three neutral;

No such SUSY partner has been observed so far. So, if they exist, they must have a mass > 1 TeV (energy explored at LHC);

(3) Kaluza-Klein theories

(1920-1926) The idea was to add a fifth space dimension to the space-time of the General Relativity(GR);

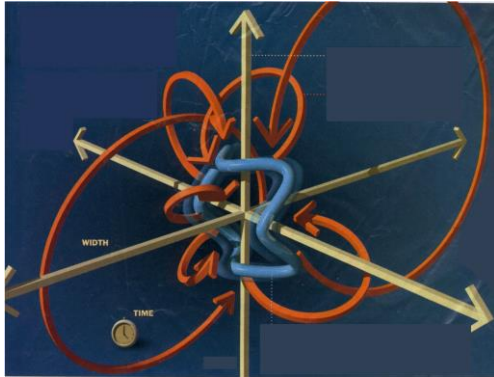
The fifth dimension is curled-up and has no effect on usual physics;

It is possible to define a field with components that in the four dimensions satisfy the field equation of the GR and with the other components which satisfy the Maxwell's relations;

Electromagnetism and GR are connected!!

The success of the Electroweak unification has revived the interest on this theory and an integer number of dimensions have been added: work in progress.

(4)String theory as ToE ?



Superstrings in 9+1 dimensions?

Particles are not point-like but little strings vibrating in a 9+1 dimensional space
 $L \sim 10^{-35}$ m (Planck length)

Standard model particles: different vibration modes, open/closed strings
GRAVITON-like particle contained (unification of SM and gravity possible).

**BUT: why did 6 dimensions disappear? how did they disappear?
is there a unique way to go from 10 to 4 dimensions?**

Axions, Magnetic monopoles Majorana neutrinos, Dyons (MM with e charge), weakly interacting massive particles (WIMPS) are proposed

So far, no experimental observations!!

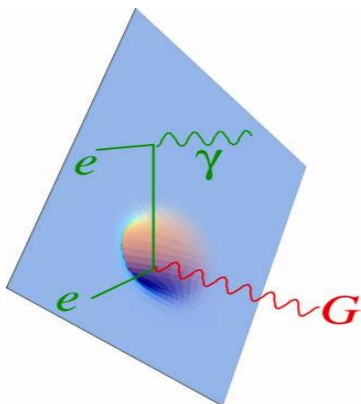
In turn the observation of gravitational waves 2016-2017 can help in the quantization of the gravity (QFT!) A possibility to study the graviton properties (gauge boson of spin2);

Why QG weakness? Exists more than 3 macroscopic dimensions of space?

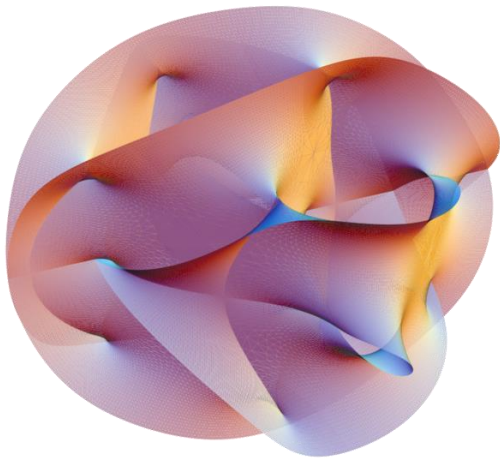
Is the graviton propagating in 4- or more dimensions of space?

Micro-black holes ?

Quantum Gravity



(5) M-theory as ToE ?



This image of the [en:Calabi–Yau manifold](#) appeared on the cover of the November 2007 issue of [en:Scientific American](#).

*) <http://en.wikipedia.org/wiki/M-theory>

M-theory*): p-brane in 11 dimension for the unification of SM+Gravity in a Theory of Everithing (ToE)

A p-brane is a physical object that generalizes the notion of a point particle to higher dimensions. For example, a point particle can be viewed as a brane of dimension zero, while a string can be viewed as a brane of dimension one.

Branes are dynamical objects which can propagate through [spacetime](#) according to the rules of [quantum mechanics](#). They have [mass](#) and can have other attributes such as [charge](#). A p -brane sweeps out a $(p+1)$ -dimensional volume in spacetime called its *worldvolume*. Physicists often study [fields](#) analogous to the [electromagnetic field](#) which live on the *worldvolume* of a brane.

Beyond SM: Scientific program at LHC 2015 -...



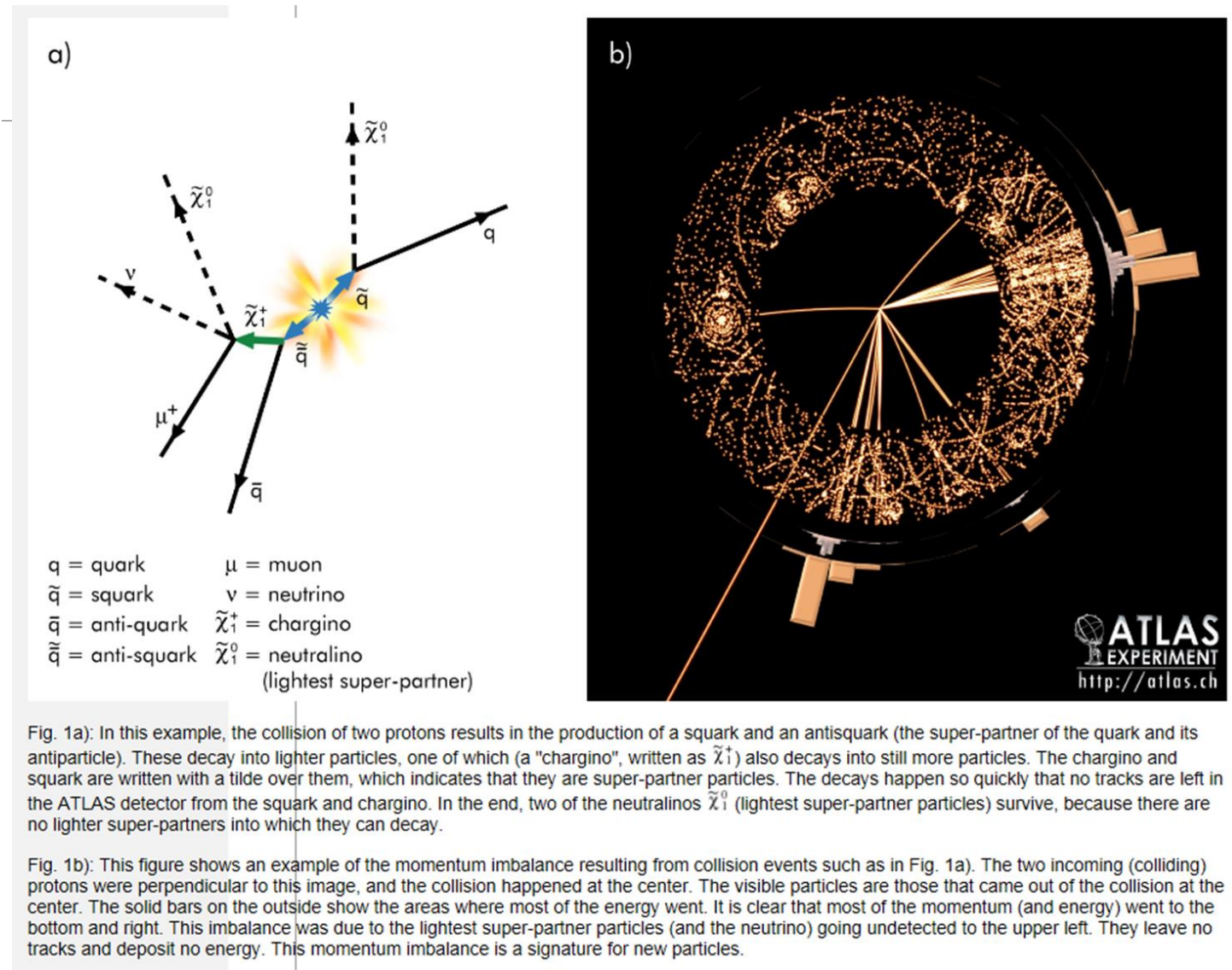
ATLAS and CMS on SUSY and extra dimensions

ATLAS and CMS

are investigating about the origin of mass, extra dimensions of space, microscopic black holes, and evidence for dark matter candidates in the Universe..

Supersymmetry

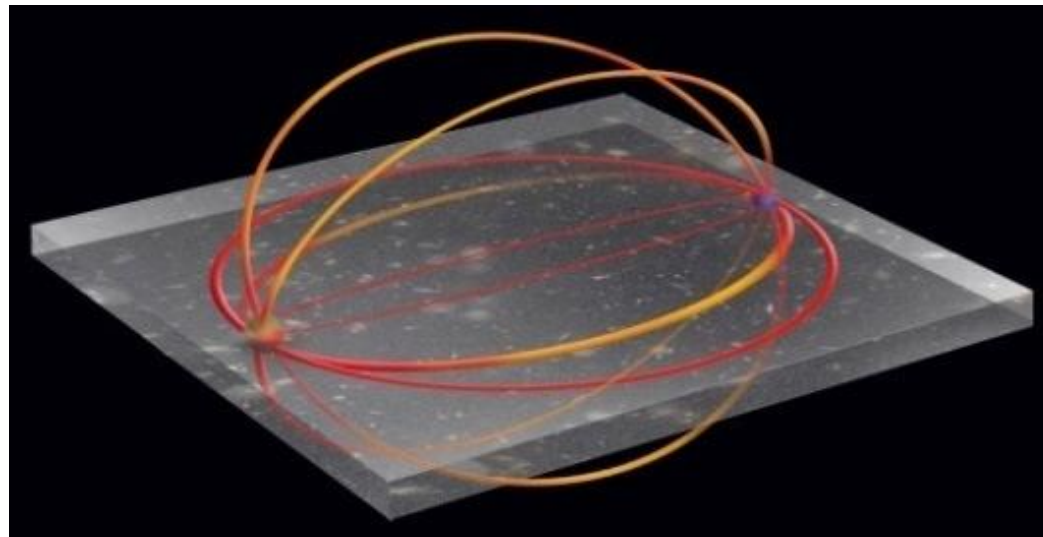
Events with substantial missing energy with high-energy electrons or muons will be indications for the production and decay of super-partners



ATLAS and CMS probing Extra dimensions for gravity

ATLAS Experiment may see evidence that extra dimensions exist via collision events in which a graviton particle disappears into other dimensions. ATLAS would detect a large imbalance of energy in the event.

CMS: This is why the detector must be as “hermetic” as possible.



10⁻¹⁰ Matter-antimatter asymmetry

LHCb (<http://lhcb-public.web.cern.ch/lhcb-public/Welcome.html#EW2013>) is dedicated to deeply investigate matter/antimatter asymmetry via decay of Beauty-particles (beauty-quark in) since weak interactions of matter differ subtly from those of antimatter. This may explain why the matter survived right after the Big-Bang.

ATLAS and CMS as well contribute on this topic

THE ATLAS EXPERIMENT AS SEEN IN ANGELS&DEMONS
THE ATLAS EXPERIMENT AT CERN APPEARS IN THE MOVIE ANGELS & DEMONS STARRING TOM HANKS

ATLAS HOME ANGELS HOME BACK NEXT

Antimatter Annihilates with Matter

It is also true that when matter and antimatter meet, they annihilate.
 Their mass is converted to energy via Einstein's equation

$$E = mc^2$$


THE ATLAS EXPERIMENT AS SEEN IN ANGELS&DEMONS
THE ATLAS EXPERIMENT AT CERN APPEARS IN THE MOVIE ANGELS & DEMONS STARRING TOM HANKS

ATLAS HOME ANGELS HOME BACK NEXT

We are lucky because...

Immediately after the Big Bang, the matter and antimatter...were *not* exactly equal

10,000,000,001 MATTER	10,000,000,000 ANTIMATTER
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NOTICE

The Great Annihilation followed

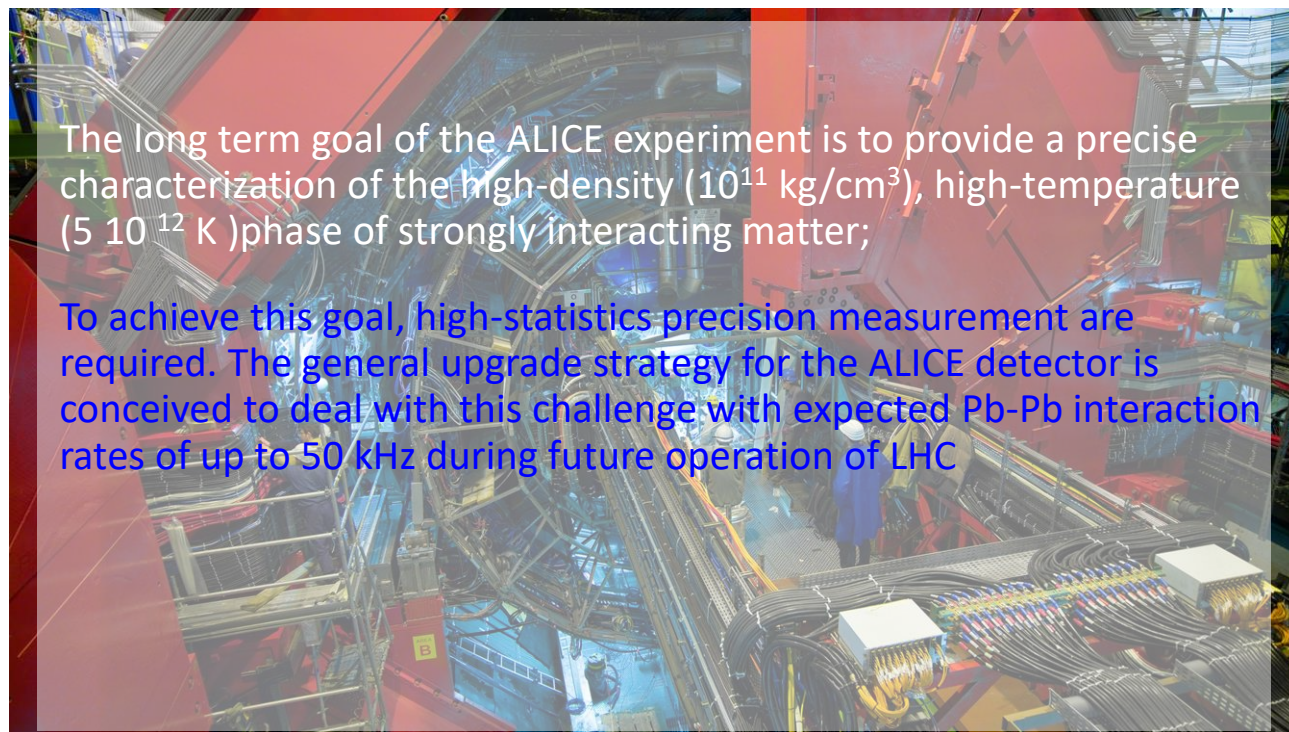
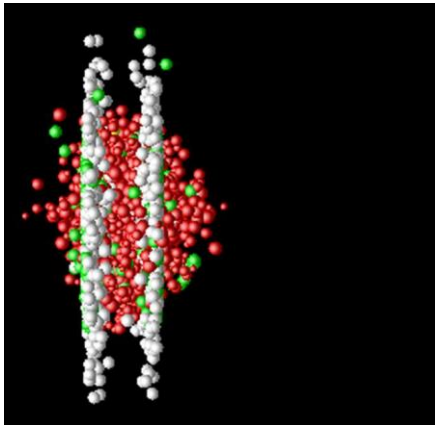
OUR UNIVERSE MATTER	1 ANTIMATTER
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NOTICE

All the antimatter, and all but a tiny part of the matter were gone...and that tiny part is us.

ALICE probing the quark-gluon plasma

Two relativistic lead-ion collision in the laboratory frame



Summary

The SM doesn't account for dark matter, dark energy,..... And as input it requires several parameters. **Nevertheless it accounts for many experimental observations!**

Theories beyond standard model try to unify Gravity and particle world:

- GUT
- Supersymmetry
- Kaluza-klaine
- String and M theories

Anyway so far no experimental evidence of predicted new particles...except the confirmation of the gravitational waves!! Data useful to study the graviton properties?

A long way to go! Young and smart students required!