

Part III

Beyond the SM: SUSY and ToE

A romantic dream for an unified description of the universe?

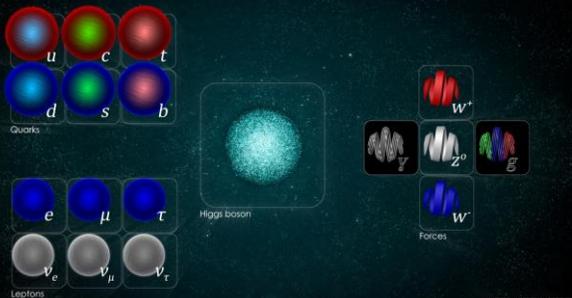
Standard Model

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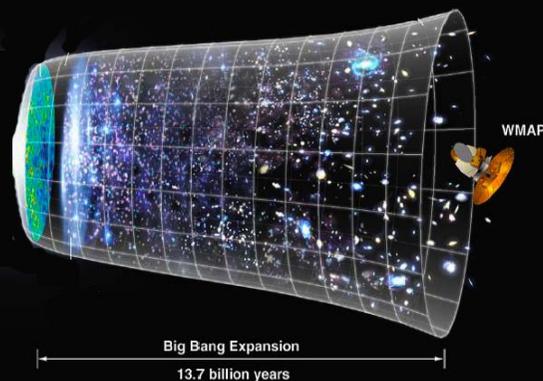
General Relativity

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Universe ?



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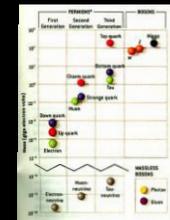
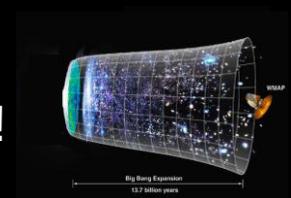


No !

What the SM doesn't explain



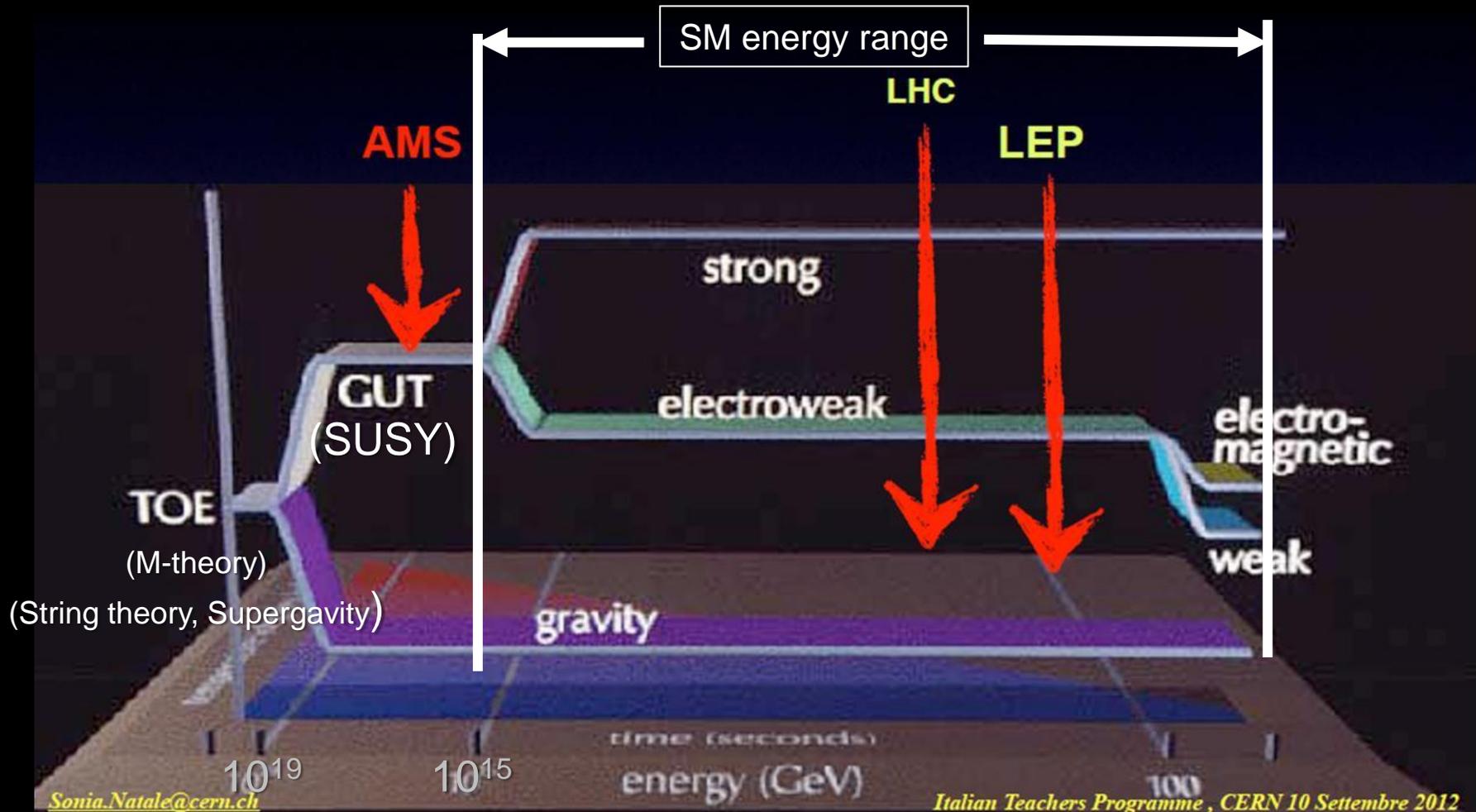
- Dark matter: galaxy rotate too fast! It exists some extra matter not visible, 23% of total mass-energy. Which type of matter?
- Dark energy: accelerated expansion of the universe, there is injection of energy. 73 % of total energy. What is generating it?
- We are in the 0.4% of the observable 4% mass-energy!
- SM doesn't incorporate the neutrino oscillation (then neutrino mass);
- Origin of mass;
- matter-antimatter asymmetry;



Beyond the Standard Model

- Theories that lie beyond the Standard Model include various extensions of the standard model through **supersymmetry (SUSY)** , such as the **Minimal Supersymmetric Standard Model (MSSM)** and **Next-to-Minimal Supersymmetric Standard Model (NMSSM)**.
- Or entirely novel explanations, such as **string theory**, **M-theory** and **extra dimensions** as these theories tend to reproduce the entirety of current phenomena, gravity included.
- Which theory is the right one towards a **Theory of Everything?**,
- Only experimental results will tell us! As from March 2015, LHC will re-start providing collisions.

Energy scale for SUSY and ToE



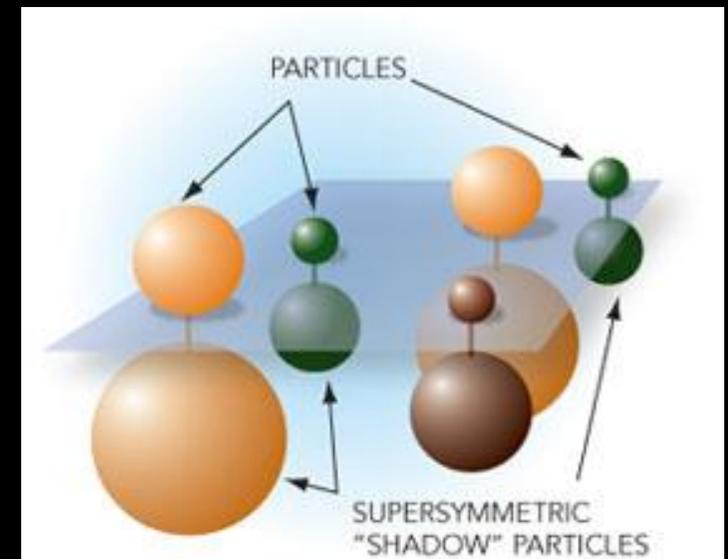
SUPERSYMMETRY (SUSY)

A connection between particles (spin 1/2) and fields (spin 1)

FERMIONS (quarks, electrons, neutrinos) interact through the exchange of BOSONS (gluons, photon, W/Z bosons)

“SUPERSYMMETRY” predicts a complete symmetry between particles of matter and carriers-of-force :

Spin 1/2 (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)

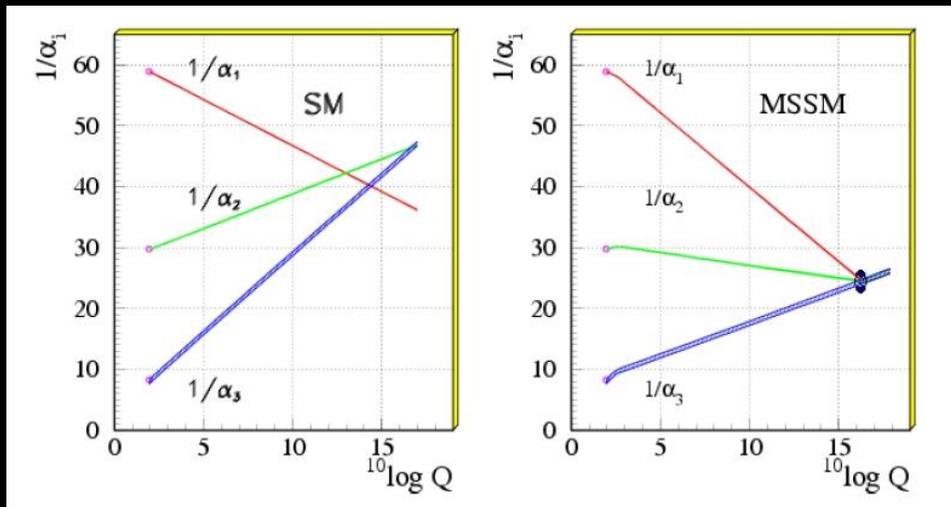


Supersymmetric BEH bosons

- But: no such SUSY partner has ever been seen. So ...if they exist, they must have a large mass (> 1 TeV)
- 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;

Why SUSY?

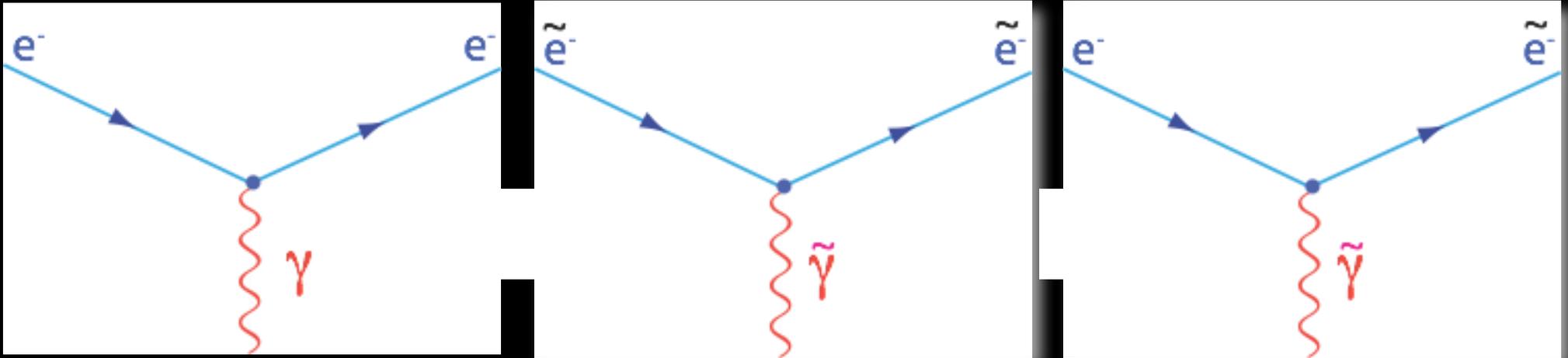
- 1) A fundamental space-time-symmetry
- 2) Predicts unification of electroweak and strong interaction at $\sim 10^{17}$ GeV



- 3) May explain the cosmological matter-antimatter asymmetry
- 4) **Lightest supersymmetric particle = dark matter ??**

Supersymmetry - easy to calculate:

Particles and 'Super-Partners' can simply be exchanged



e^- = electron

γ = photon

\tilde{e} = selectron

$\tilde{\gamma}$ = photino

String theory as ToE ?

What is a particle?



Superstrings in 9+1 dimensions?

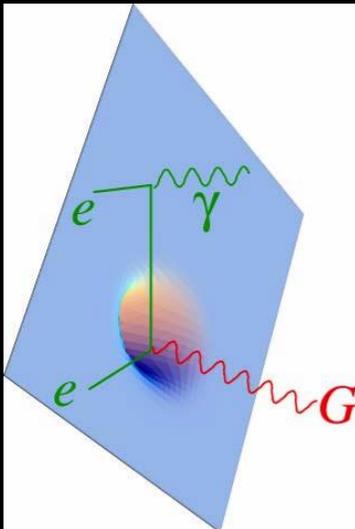
Little strings of string energy vibrating in a 9+1 dimensional space ?

$L \sim 10^{-35}$ m (Planck length)

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

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

Quantum Gravity

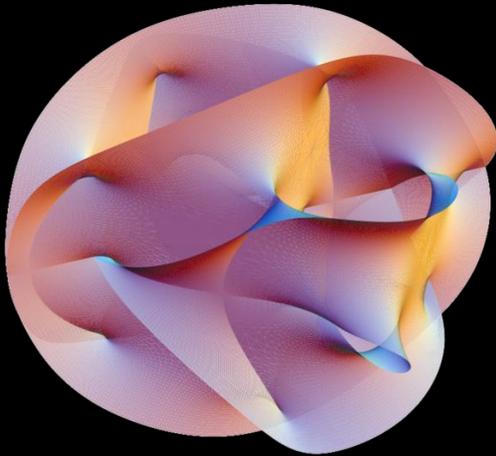


QG weakness: more than 3 macroscopic dimensions of space?

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

Micro-black holes ?

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](#).

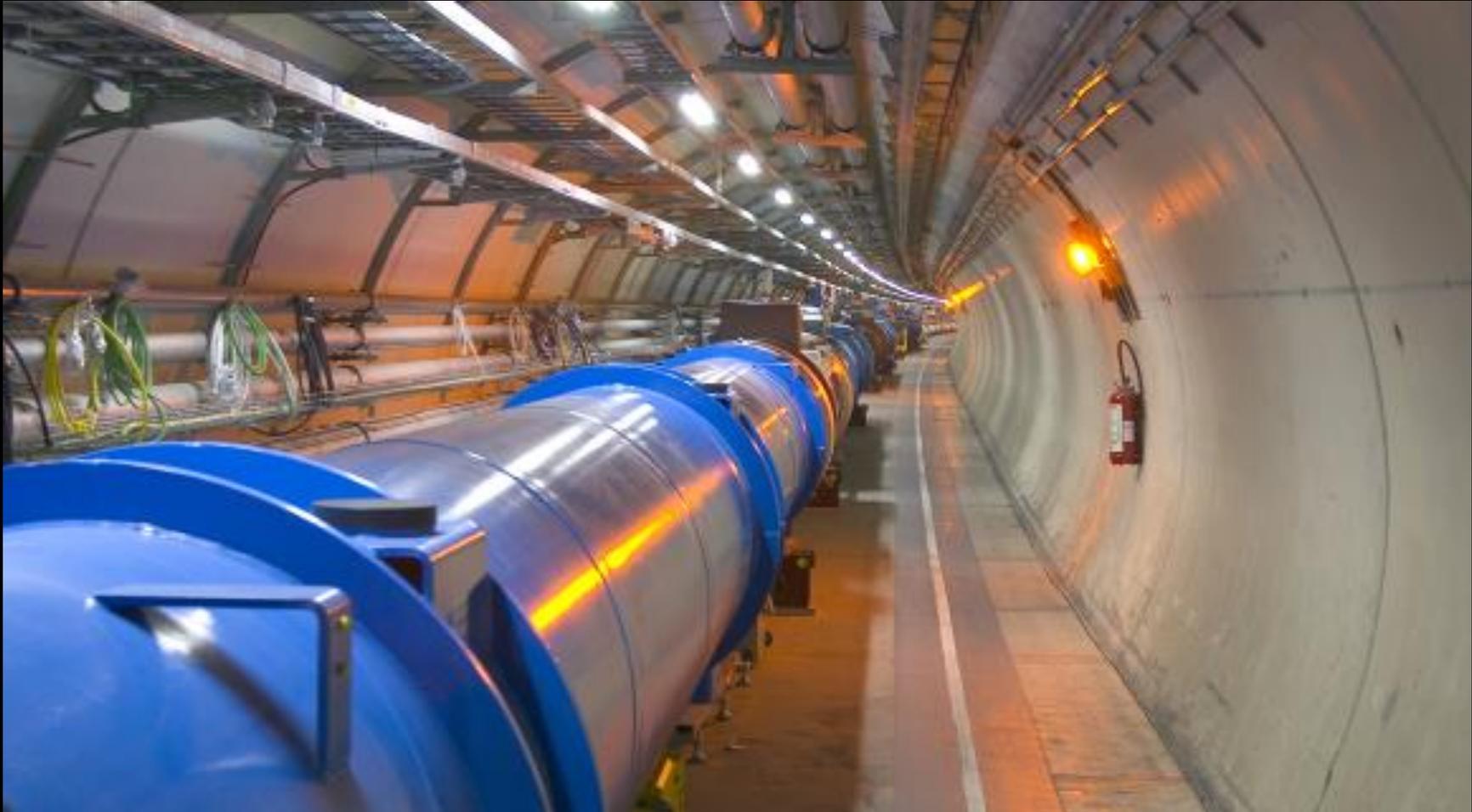
*) <http://en.wikipedia.org/wiki/M-theory>

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.

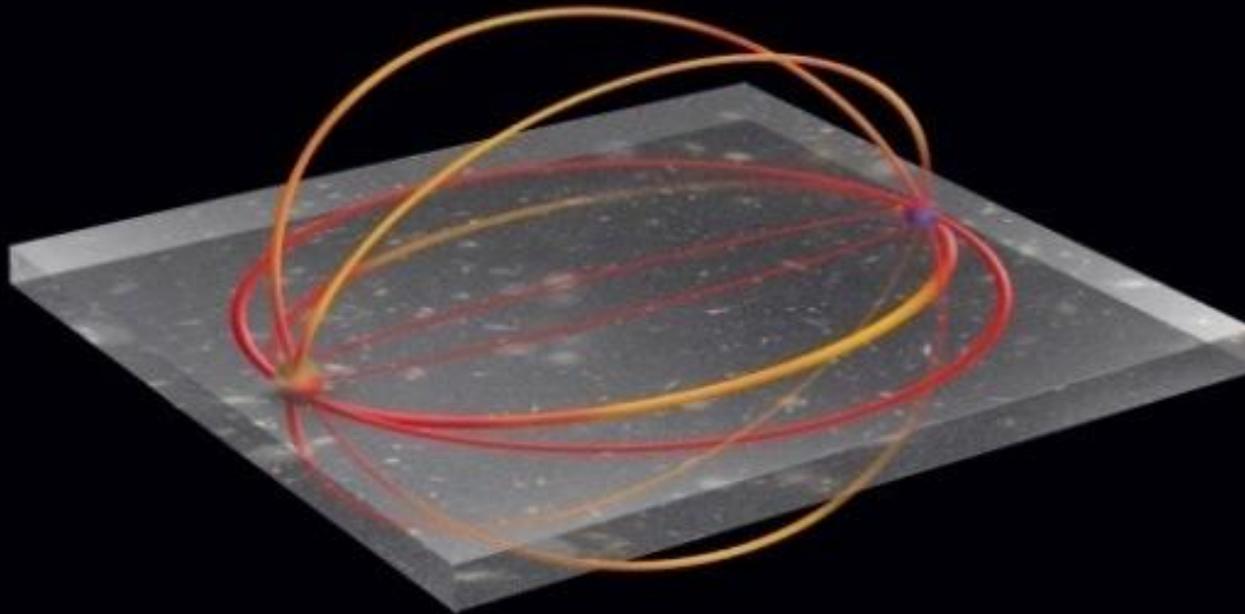
Scientific program at LHC 2015 -...



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 EXPERIMENT 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

$$E = mc^2$$
A diagram showing two human silhouettes, one blue (matter) and one orange (antimatter), facing each other. They are surrounded by a bright, glowing explosion of light, representing the annihilation process. The blue silhouette has two '+' signs on its chest, and the orange silhouette has two '-' signs on its chest.

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We are lucky because...

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

10,000,000,001 MATTER NOTICE	10,000,000,000 ANTIMATTER
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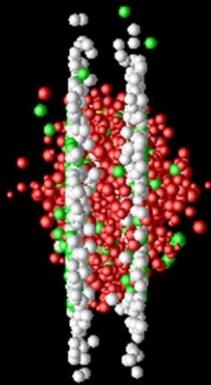
The Great Annihilation followed

OUR UNIVERSE 1 MATTER NOTICE	ANTIMATTER
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All the antimatter, and all but a tiny part of the matter were gone...and that tiny part is us.

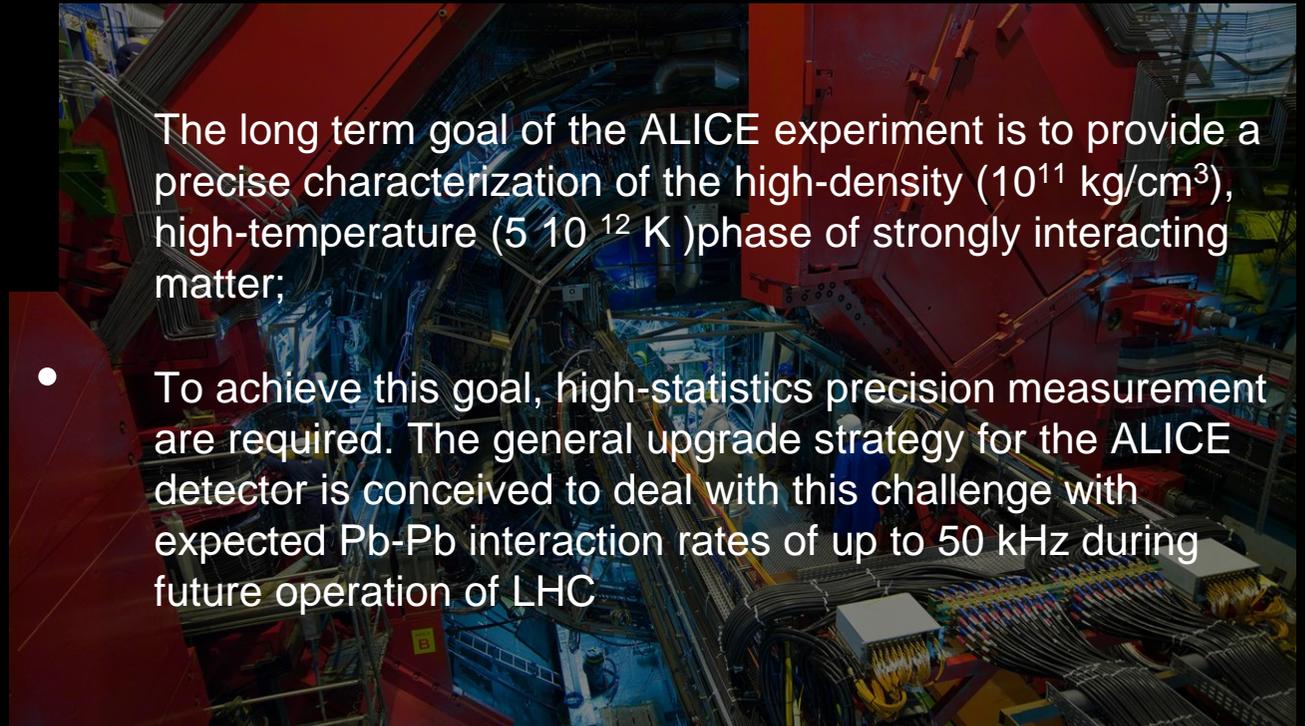
ALICE probing the quark-gluon plasma

Two relativistic lead-ion collision in the laboratory frame



The long term goal of the ALICE experiment is to provide a precise characterization of the high-density (10^{11} kg/cm³), high-temperature ($5 \cdot 10^{12}$ K) phase of strongly interacting matter;

- To achieve this goal, high-statistics precision measurement are required. The general upgrade strategy for the ALICE detector is conceived to deal with this challenge with expected Pb-Pb interaction rates of up to 50 kHz during future operation of LHC



A philosophical experiment: an empirical study of knowledge production at the LHC

Arianna Borrelli - Wuppertal University <http://indico.cern.ch/event/232108/>

- “Which models do you prefer?”
- “On which model are you working?”

Interviews

Experimental physicists:

Jamie Boyd (ATLAS, CERN)
Lutz Feld (CMS, RTWH Aachen)
Fabiola Gianotti (ATLAS, CERN)
Andrei Golutvin (LHCb, IC London, ITEP, CERN)
Cigdem Issever (ATLAS, Oxford)
Vivek Sharma (CMS, UC San Diego)
Guido Tonelli (CMS, Pisa University)

Theoretical physicists:

Luca Di Luzio (KIT Karlsruhe)
John Ellis (CERN, King's College London)
Christophe Grojean (CERN, CEA Saclay)
Michael Krämer (RTWH Aachen)
Michelangelo Mangano (CERN)
Chris Quigg (Fermilab)

What do we expect ?

Arianna Borrelli - Wuppertal University <http://indico.cern.ch/event/232108/>

Some tentative conclusions:

- these results do not support the traditional pictures of physicists comparing and preferring models/theories according to some criteria
- models are rather regarded as exploratory tools for research than as serious candidates to a theory of new physics. Yet the general approaches (SUSY, extra dimensions...) are taken seriously ("theoretical cores" Borrelli 2012)
- LHC results did not change much the pattern of (rather feeble) abstract preferences, but seem to have further eroded the belief in individual models - yet interestingly SUSY is somehow slightly, relatively better off (Sept. 2012!)

Outlook: alternative theoretical schemes

- there is little claim of strong motivations to prefer specific BSM-models, but HE-physicists are strongly motivated to invest resources in the search for new physics in general ---> Pickering's "opportunism in context": success in the search would have a high pay off in terms of new research possibilities
- experimenters reject preferences as a bias, and it is unclear how choices on models in large collaborations are made ----> Karin Knorr-Cetina: choices in HEP-experimental collaborations are results of long processes of consensus-formation rather than of point-like decisions by "leaders" or "committees"

Summary parts II and III

- The SM doesn't account for dark matter, dark energy,.....
- String and M-theory for unification of SM and General relativity?
- Have the physicist preferences?