[#newphysics]

year 10, number **18** / 2015

asimmetrie

half-yearly magazine of the Italian
National Institute for Nuclear Physics

asimmetrie

Dear Readers,

The discovery of the Higgs boson came at the end of a long journey, where the direction was marked, but the road had to be built. Fifty years of efforts and, thanks to a series of innovative technologies and a clear vision, at last came the LHC accelerator and the long awaited discovery.
So what now? Now we are looking out onto a world we don't know, where there are no paths, and even the directions to be followed aren't very clear. Sure, we know there is something out there, indeed, there is rather a lot. There is dark matter, with its very evident gravitational effects. Some people maintain that the extinction of the dinosaurs was due to its effects. The speed at which the universe is expanding, which increases with the passage of billions of years and that we, in the absence of any explanation, attribute to a mysterious dark energy, is another enigma to be solved. In the world of conventional particles, instead, the neutrino with its uncertain nature and mass, is waiting to be placed in a model other than the standard one according to which it was attributed various properties.
And what shall we do to investigate this unknown world? Which direction should we take and which paths should we build? Research into dark matter relies on the future of the LHC at even higher energy, on capturing its interactions in the silence of the underground detectors, and on the signals observed by the satellites that scan the universe. The study of dark energy, rather less advanced, is entrusted to terrestrial telescopes and satellites, which will at least be able to tell us whether this continuous acceleration has always been present or if it varies in time. To study neutrinos, highly refined experiments are under construction and will operate away from the disturbance of cosmic rays, for example, in the depths of the Gran Sasso (a mountain in Italy, ed.), or in mines and observatories under the sea or ice.
We are using a successful and sustainable combination of technology with patience and method to make progress in science.

Happy Reading.

Fernando Ferroni
INFN President

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[#newphysics]

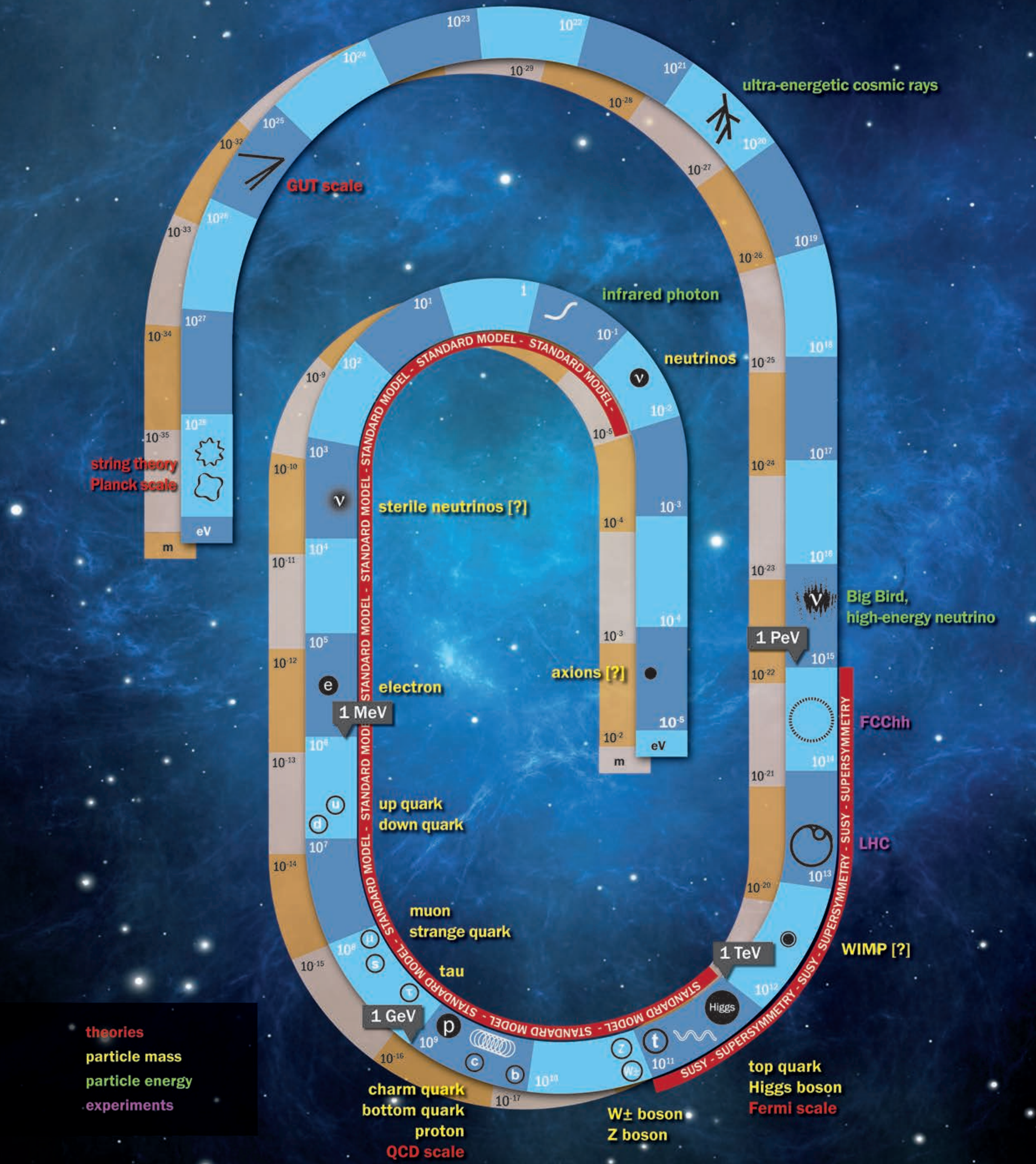
Today is already tomorrow

Physics after the Higgs boson

by Guido Altarelli

After the first phase of the Large Hadron Collider (LHC) experiments at CERN, particle physics is faced with a new paradox. On one hand, the theory of strong and electroweak interactions, the so-called standard model, has achieved some outstanding successes, like the discovery of the Higgs boson, passing precision tests of every type, etc. On the other, strong theoretical reasons (mainly the question of hierarchy or naturalness) and evident experimental problems (for example the nature of dark matter) suggest that the standard model theory is not entirely complete and that signs of new physics should actually already have emerged from the experiments in the accelerators. Paradoxes are always very interesting, because solving them can lead to a real turning point in the development of new theories in physics.
Completed by the Higgs boson, the standard model is a perfectly functional theory: it is in fact re-normalisable, which means that, after a finite number of experimental measurements, the theory is well "calibrated" and can, in principle, be used to predict the result of any other measurement, without ambiguity up to the highest energies. As far as our universe is concerned, if the standard model is deemed to be entirely valid, the universe is meta-stable: it could collapse into a new and completely different state. Fortunately, the likelihood of something like that happening in the time comparable to the age of the universe is practically zero.
Given that decades of experiments in accelerators have always reaffirmed the validity of the standard model, why should we continue to invoke new physics? Above all, because we have some very impressive experimental evidence "from the sky", or rather from astrophysics and cosmology: almost the entire density of energy in the universe is vacuum energy (around 73%), which can be described in terms of a non-null cosmological constant called dark energy (see p. 31, ed.) and dark matter (approx. 22%, see p. 25, ed.), neither of which is included in the standard model. Furthermore, the standard model does not account for the properties of neutrinos (masses and mixings) (see p. 34, ed.) that, as already established, have a non-zero mass (at least two of them), which is however much smaller than that of quarks and charged leptons. Besides, the standard model

a.
On 4th July 2012, Rolf Heuer (Director of CERN), Fabiola Gianotti (then project leader of the ATLAS experiment, now Director designate of CERN) and Joe Incandela (project leader of the CMS experiment at that time) announced the discovery of the Higgs boson, contributing to the success of the standard model of particles.


ultra-energetic cosmic rays
GUT scale
string theory
Planck scale
infrared photon
neutrinos
sterile neutrinos [?]
electron
1 MeV
axions [?]
Big Bird,
high-energy neutrino
1 PeV
FCChh
LHC
up quark
down quark
muon
strange quark
tau
1 GeV
1 TeV
WIMP [?]
Higgs
charm quark
bottom quark
proton
QCD scale
W± boson
Z boson
top quark
Higgs boson
Fermi scale
STANDARD MODEL
SUSY - SUPERSYMMETRY
m
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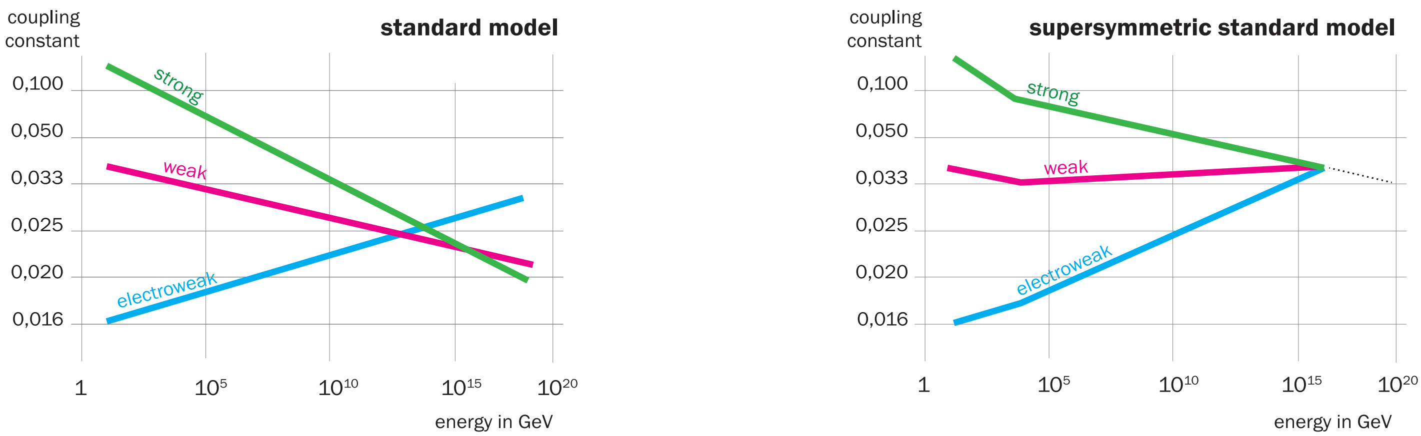
theories
particle mass
particle energy
experiments

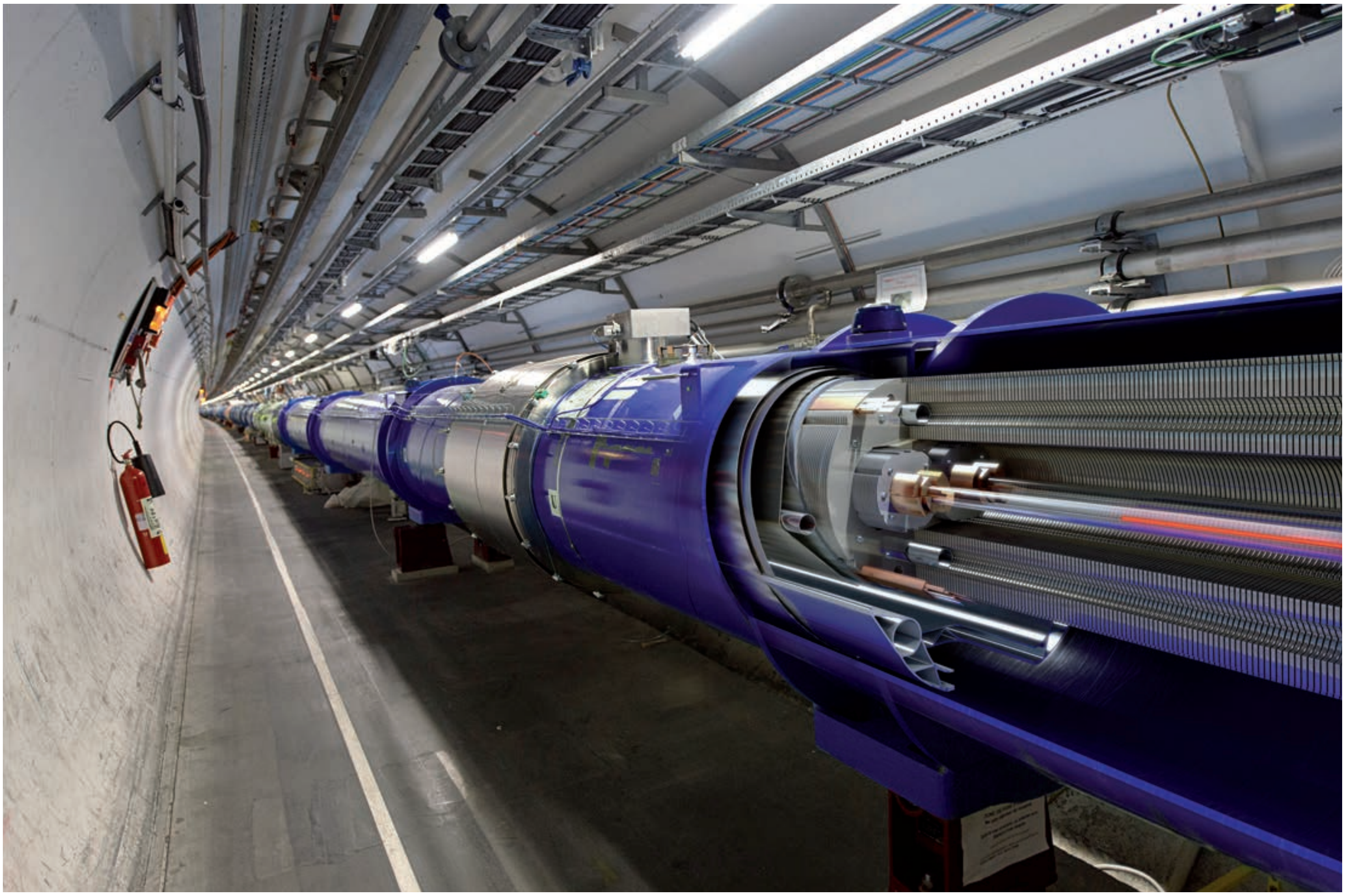
b.
The boxes in this figure similar to those in "snakes and ladders" represent the different energy scales (in blue) and the corresponding distance scales (in orange). The correspondence between energy, expressed in electron volts, and distance, expressed in metres, is shown by the equation $E(eV) \sim 2 \times 10^{-7}/L(m)$, since small distances correspond to high energies and vice-versa. The figure shows the masses of the particles of the standard model already known (electrons, muons, tau, different types of quarks, neutrinos, Higgs boson, etc.), those of other as yet hypothetical particles (axions, sterile neutrinos...) and the energies characteristic of certain physical phenomena observed or attainable in particle accelerators.

cannot explain baryogenesis, that is the predominance of matter over antimatter in the universe (see p. 27, ed.).
Then there are conceptual issues that "call upon" new physics. These include the fact that the gravitational interaction (gravity in layman's terms) is outside the scope of the standard model and that the question of the quantum theory of gravitation remains unsolved (string theory could produce a solution, see p. 42, ed.).
The quantum effects of gravitation are only appreciable at massively higher energies than those explored in the LHC (in the region of 10 TeV, or 10^4 GeV) and thus on the so called Planck scale, in the region of 10^{19} GeV. Extrapolating the known theories to slightly smaller scales that are, nonetheless, still well beyond current experimental limits, provides some very interesting clues about the behaviour of new physics. In fact, the (calculable) evolution of the gauge coupling constants (the parameters that determine the intensity of the different fundamental interactions) as a function of the energy scale indicates that these tend to assume the same value on the scale of grand unification (10^{15} GeV): this behaviour is predicted by the Grand Unification Theories, abbreviated as GUT, according to which the three interactions that exist at the "low" energies studied in the LHC (strong, weak and electromagnetic) are based upon a single fundamental interaction on a very high energy scale (see fig. c, p. 9). Unification on the same scale is however only approximated in the standard model and could also lead to a prediction for proton decay that is too fast with respect to existing experimental limits. Both of these problems could be overcome if we had a new physics, or rather a theory that goes beyond the standard model, on energy scales below that of the grand unification.
The solution to many of the problems with the standard model can be found in a more fundamental theory (in which the standard model is the limit of low energy, see p. 11, ed.), perhaps in a theory on the Planck scale, which also includes the gravitational interaction in unification. For example, the solution to the flavour problem, i.e., the explanation of the three generations of quarks and leptons and the mysterious hierarchy between their masses might not be accessible at low energy. There are questions with the standard model that require (such as the hierarchy problem) or suggest (such as dark matter) a solution in proximity to the electroweak scale. The hierarchy problem consists of the fact that, in the standard model, the value of the Higgs boson's mass depends heavily on the values of the masses of any new particles that exist on higher scales. In other words, this hierarchy of masses means that the measured value of the mass of the Higgs boson (equal to 125 GeV) is the consequence of a cancellation of terms that could be much higher, due to coupling between the Higgs boson and other new particles. For this mechanism to be "natural", these new particles must not be too heavy, in that the terms induced by their coupling with the Higgs boson must not be much higher than the observed value of the latter's mass. Thus, in order to extrapolate the theory up to the scale of grand unification or the Planck scale, without having to "invoke" an extremely accurate and un-natural "fine tuning" of these cancellations, we need to expand the theory and introduce new particles that may have masses not far from the electroweak scale. The most studied theoretical method is that of supersymmetry (or SUSY, from SUper SYmmetry), a symmetry between bosons and fermions, according to which every known particle in the standard model is associated with a corresponding supersymmetrical partner or s-partner (see page 14, ed.).
The dependency on high scales cancels out for higher energies of the masses of the supersymmetric particles (or at least some of them) and this expanded standard model (for example like the so-called minimal supersymmetric standard model) is insensitive to the presence of even heavier particles, thus overcoming the hierarchy problem. Furthermore, if supersymmetry were an exact symmetry, the s-partners would have exactly the same mass as the corresponding particles of the standard model. However, since none of these new objects has ever been observed, we have to conclude that they have a greater mass, which means that supersymmetry must only be an approximate symmetry or, in jargon, a broken symmetry. However, to solve the hierarchy problem and satisfy the need for "naturalness", the s-partners must not be too much heavier than the particles of the standard model. That is why many were expecting new physics on the scale of 1 TeV, and therefore accessible by the LHC (and even by LEP2, the Large Electron-Positron collider in operation at CERN until 2000). Today, data obtained both from research into new particles and the exploration of their possible virtual effects require a high



level of fine-tuning. Nature doesn't seem to care much about our idea of "naturalness"!
Supersymmetry has many strengths apart from those of a purely theoretical nature: it corrects the unification of gauge coupling on a scale of about 10^{16} GeV, it guarantees sufficient stability for protons and has ideal dark matter candidates, specifically neutralinos. Neutralinos are special WIMPs (Weakly Interacting Massive Particles, meaning 'heavy particles that interact weakly'). They are, in fact, particles with a mass of between a few GeV and a few TeV, they are stable (or do not decay) and their interactions are such as to ensure that they are produced in the primordial universe with the abundance required by cosmological observations. WIMPs are the subject of intense research, not only in the LHC, but also in experiments in laboratories and in space, beneath the sea and under the ice.
Solving the problem of dark matter, which suggests the existence of new particles with masses of less than the TeV, is a crucial issue for today's particle physicists.
Nobody has even the slightest idea of the relevant mass interval: this ranges from axions (hypothetical bosons without electric charge and that interact rather little with matter), with a mass of around 10^{-5} eV, to sterile neutrinos (not subjected to any interaction between those present in the standard model) with a mass of a few keV, to WIMPs and other more exotic candidates too.
For other phenomena that point to new physics there are, instead, some very plausible extensions of the standard model. For example, the minuscule masses of neutrinos can be elegantly explained by the so-called see-saw mechanism (see p. 34, ed.).
Where does the community of physicists stand on the "naturalness" issue? Many think the problem might go away at least in part, if the much invoked new physics decides to appear in the second phase of the LHC at 13-14 TeV, which has just started. Many models have been developed where new physics is actually close-by, but with characteristics that have so far made it invisible. Others contemplate more exotic scenarios: dependency on the high masses we have already talked about would do no harm, if there were no particles up to the Planck scale and if a mechanism due to the unknown theory of gravity could resolve the problem of naturalness at those high energies. In this case though, the questions of dark matter, the masses of neutrinos and baryogenesis would all have to be resolved by physics around the electroweak scale. This is possible by assuming the existence of new light sterile neutrinos (one of a few KeV and two others of a few GeV).
Other physicists inspired by the question of the cosmological constant see an "anthropic" solution to the problem, in which the values of certain parameters are explained not on the basis of theoretical predictions, but from the

c.
The coupling constants of the strong, weak and electromagnetic interactions as a function of the energy scale according to the standard model (left) and according to the minimal supersymmetric standard model (right). In the supersymmetric model, the three coupling constants assume the same value at an energy scale of around 10^{16} GeV, as envisaged in the grand unification scenarios.



observation that different values would give rise to a universe that would be completely different from the one observed. In the case of the cosmological constant, the question of "naturalness" consists of the fact that this is many orders of magnitude smaller than would be expected on the basis of theoretical estimates. However, the observed value is close to the maximum that is possible in order to permit the formation of galaxies and thus our very existence. Therefore if our universe is just one of the many that are continuously being produced by the vacuum through quantum fluctuations, as predicted by some cosmological theories, each of which contains a different physics, it might be that we live in a very exceptional universe, which is rather unlikely from a theoretical perspective, but the only "anthropic" one, i.e. the only one where we are able to exist.

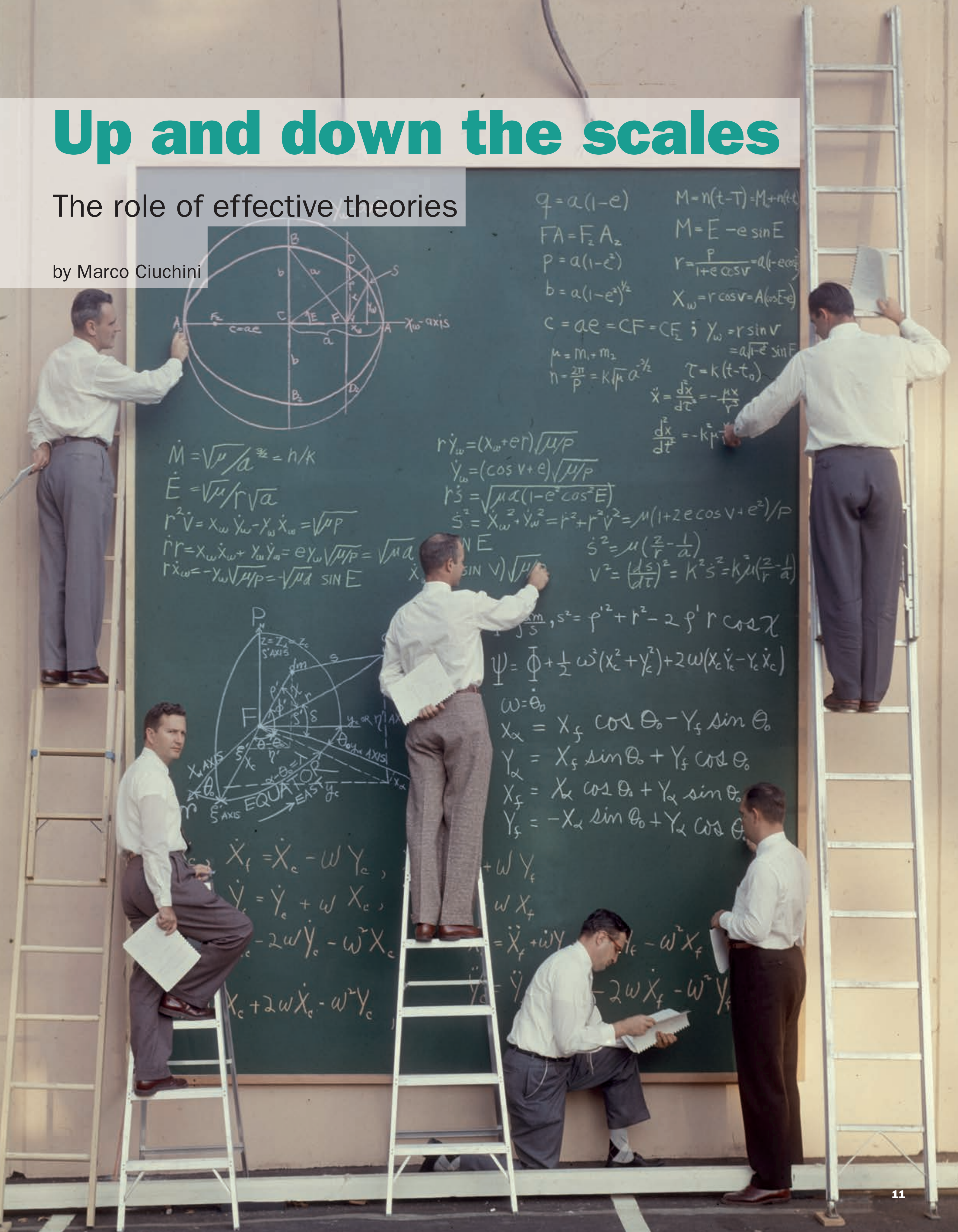
d.
A small part of the 27 km-long LHC accelerator tunnel, just outside Geneva on the Swiss-French border, where proton beams started circulating again on 4th April 2015.

Biography
Guido Altarelli has been professor *emeritus* of theoretical physics at the University of Roma Tre. He was Director of the Rome Section of the INFN from 1985 to 1987. Between 1987 and 2006 he worked at the Theory Division of CERN, and was Theory Division Leader from 2000 to 2004. He passed away on the 30th of September 2015.

Up and down the scales

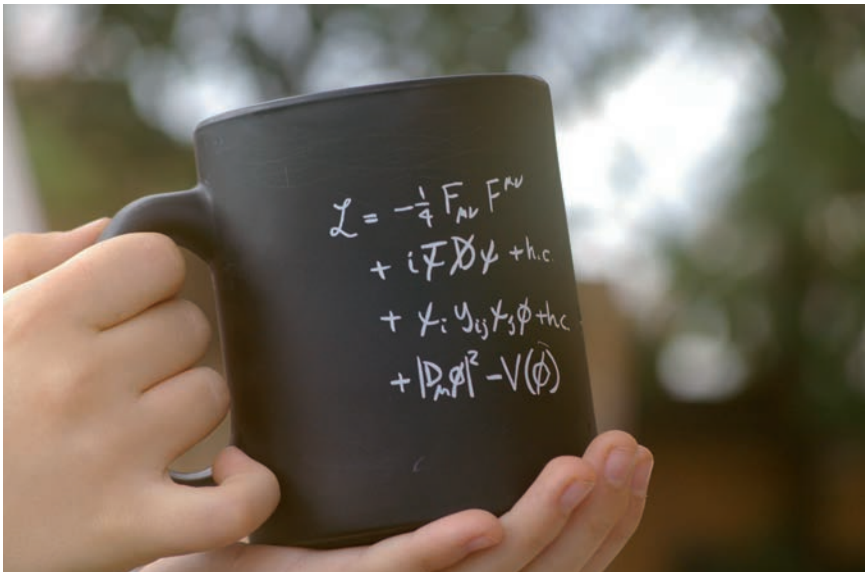
The role of effective theories

by Marco Ciuchini



Physics is characterised by the presence of scales: scales of distance, energy, time, speed or any other physical quantity, fundamental scales or scales related to a specific problem. Interesting physical phenomena occur at very different scales: galaxy clusters collide at distances in the region of 10^{22} metres, the collision of two quarks in an LHC takes place at around 10^{-19} metres.
Were a physical phenomenon to depend on what happens at all scales in the same way, it would be really very difficult to describe. Fortunately (albeit with some notable exceptions) the separation of scales applies: as a general rule, physical phenomena occurring at a given scale are not affected by the details of physics associated with very different scales and in many cases large physical quantities change when passing from one scale to another. That is why, when there are several scales at play, it is convenient to use a non-exact theory which, however, describes the relevant physics at a given scale in the most appropriate way. This is what physicists call an effective theory, as opposed to the fundamental theory which is ideally valid at all scales.
Let us imagine, for example, that we want to calculate the path of a ball on a billiard table. We think we can use a fundamental theory, namely relativistic mechanics based on Einstein's special theory of relativity. We could certainly use it, but we don't usually: why? Because the problem involves two very different scales: the typical velocity of the ball, let's say of around 1 m/s, and the speed of light $c = 3\times10^{9}$ m/s, which is a fundamental constant of the theory. It is more convenient to introduce an approximate theory, developed by considering the velocity of the ball as a distortion of the limiting case considering the speed of light as infinite. The effective theory developed using the first adjustment at the limiting case is nothing more than Newtonian (classical) mechanics, the theory we all studied at school, since this, though an approximation, is the most appropriate and convenient theory for describing objects moving at speeds much smaller than the speed of light, i.e. all the objects of which we have direct experience.
In the field of elementary particle physics (both relativistic and quantum), all physical scales are based on energy scales (which explains why particle physicists always use multiples of the electron-volt). The fundamental theory must thus describe physics at all energies including all the elementary particles that exist, even those we have yet to discover!

As mentioned earlier, effective theories can, on the other hand, be conveniently used to describe low-energy processes. Yes, but low compared to what? Some energy scales are associated with fundamental interactions: the scale of strong interactions (or QCD scale), about 1 GeV; the Fermi scale, in the region of 100 GeV, related to the masses of W and Z bosons, mediators of weak interactions; the Planck scale, equal to 10^{19} GeV, related to the universal gravity constant. Whenever we consider processes with typical energies that are much smaller than one of these fundamental scales (there are others too, such as those for the masses of heavy fermions), we can define an effective theory obtained, like in the example of classic and relativistic mechanics, as a distortion at the limiting case in which we consider the energy at the highest scale in the theory as infinite. This theory only contains the relevant particles at the scale of the processes being considered, while the heaviest particles are generally uncoupled. Furthermore, if we also know the theory at the high scale, we will be able to calculate the adjustments at the limit case to arbitrarily high precision. The effective theory can still be very useful even without knowing the theory at the highest scale: it allows us to parameterise our ignorance in terms of a finite number of constants and so as to respect the known properties of physics at the low scale.
To date, the standard model, the benchmark theory for particle physics, is in accordance with all observed phenomena. Is it a fundamental theory or is it the first approximation of an effective theory, applicable at the energies reached by our accelerators, say, at the Fermi scale (although the LHC has now started exploring the TeV scale, 10 times bigger)? The standard model does not contain gravity (because we have yet to learn how to include it!), so something must definitely change at the Planck scale, where the gravitational interaction is no longer negligible. It is therefore natural to think of the standard model as an effective theory obtained by considering the Planck mass as infinite. There are, however, several theoretical and observational reasons (dark matter, to name but one) that suggest there might be an intermediate energy scale between the Fermi scale and the Planck scale, associated with the mass of new heavy particles. This scale, called the scale of new physics, and these particles, not included in the standard model, are the new physics we are looking for.
The problem of the scale of new physics is that we think it exists, but we don't know for



a.
The equation on the cup describes the standard model.

certain its magnitude: if it is less than the energy that can be reached in the LHC, we will soon be able to observe the new particles and test whether and with which of the extensions of the standard model developed over the last 40 years (supersymmetry, again to name just one) they are compatible. Once we have discovered the theory of new physics, the standard model will continue to be valid as an effective theory for processes on the Fermi scale, and we will also be able to calculate the corrections due to the presence of the new particles. If instead, we do not succeed in producing new particles, and have to wait for a higher energy accelerator (see p. 20, ed.), we can try to see if there are any deviations from the predictions of the standard model due to the presence of new heavy particles. Indeed, Heisenberg's uncertainty principle states that particles make a virtual contribution to physical processes at a certain energy level, even if they are too heavy to be produced. In this game, the effective theory can be used in two ways: adopting an approach from the high scale to the low scale, attempting to "guess" the theory according to the scale of new physics, typically on the basis of some new symmetry, and using this to calculate the corrections to the "standard model" effective theory, or adopting the opposite approach, from the low to the high scale, using experimental data to try to identify the possible corrections to the standard model in the hope that this information will lead to the new theory.
Which method is more useful? The standard model was proposed in the 1960s using both approaches: it is based on symmetry, which however was identified using an effective theory, called the V-A theory, used in previous years to describe weak interactions. Vice versa, the Higgs mechanism for spontaneous symmetry breaking, which is also an essential ingredient for constructing a realistic model, was introduced without any true observational stimulus, by analogy with problems of the physics of condensed matter and only now, following the discovery of the Higgs boson, can we start to use effective theories to describe its couplings. We know from experience that we must use all the methods available to us in our search for new physics!

Biography
Marco Ciuchini is a theoretical physicist, director of research and head of the INFN Roma Tre division. He studies the phenomenology of elementary particles and is mainly concerned with quark flavour physics.

Web links

http://en.wikipedia.org/wiki/Effective_field_theory

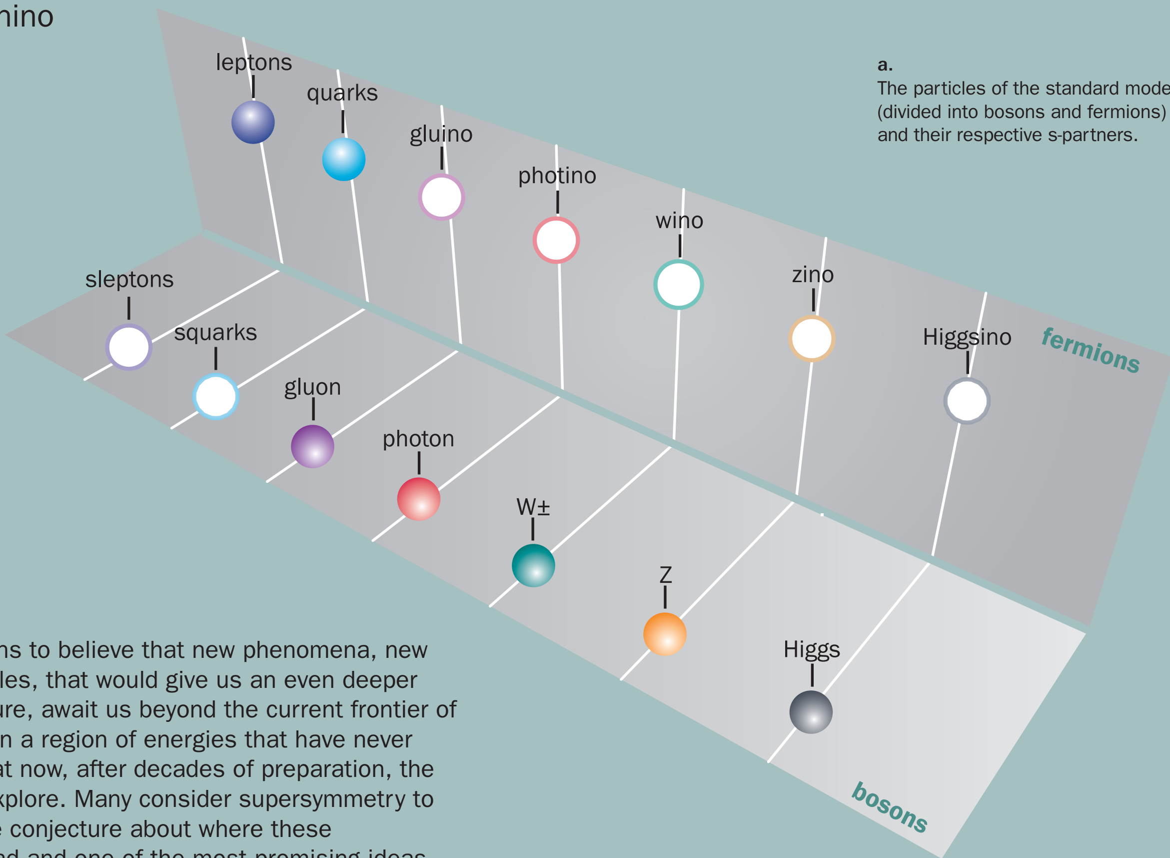
http://www.preposterousuniverse.com/blog/2013/06/20/how-quantum-field-theory-becomes-effective/

http://ocw.mit.edu/courses/physics/8-851-effective-field-theory-spring-2013/

The world starting with an "s"

Supersymmetric extensions of the standard model

by Andrea Romanino



a.
The particles of the standard model (divided into bosons and fermions) and their respective s-partners.

There are valid reasons to believe that new phenomena, new particles, new principles, that would give us an even deeper understanding of nature, await us beyond the current frontier of the standard model, in a region of energies that have never been reached and that now, after decades of preparation, the LHC has started to explore. Many consider supersymmetry to be the most plausible conjecture about where these explorations might lead and one of the most promising ideas for new physics beyond the standard model.

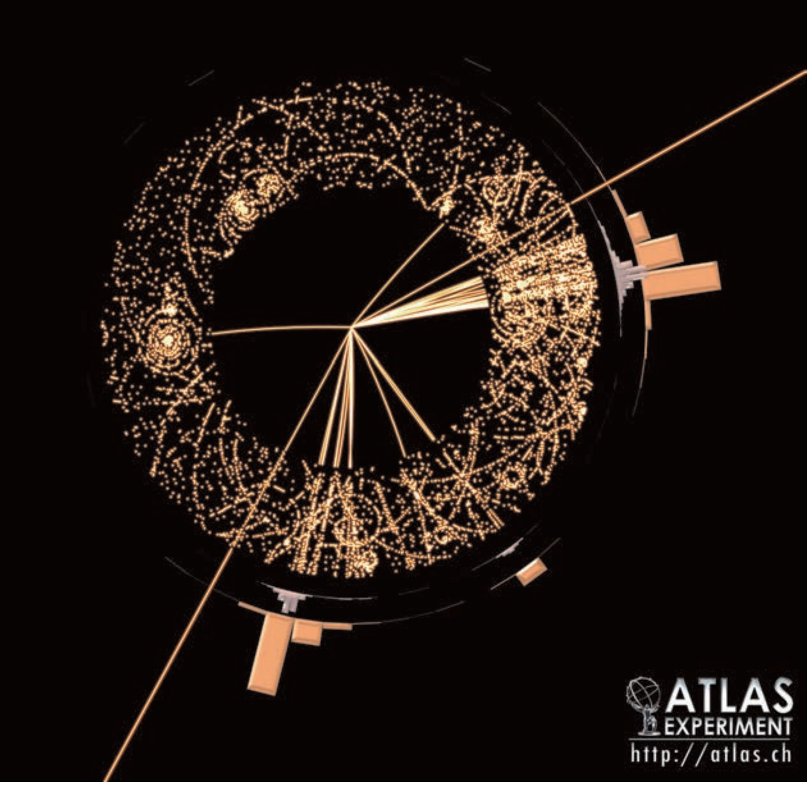
The symmetry concept has played a crucial role in the development of fundamental physics. Think, for example, of the spacetime symmetry that forms the basis of the theory of relativity, the interpretation of fundamental forces in terms of symmetry groups or the idea of spontaneous symmetry breaking that underlies the discovery of the Higgs boson; nature really does seem to show a partiality for symmetry. Supersymmetry is a new kind of symmetry. Unlike the known symmetries, it connects particles with very different characteristics and behaviours, bosons and fermions. Examples of fermions are the particles that constitute known matter, examples of bosons are the Higgs particle, and those which transmit forces (photons, gluons and W± and Z bosons), and they differ in their angular momentum (spin): the first have half-integer spin, the latter have a full integer spin. If this symmetry exists in nature, for every boson there would be an as yet unknown matching fermion and vice versa (see fig. a): supersymmetric partners or s-partners.

The supersymmetric partner of a fermion is denominated by adding the prefix "s" to the name of the corresponding fermion, while the supersymmetric partner of a boson is called by the name of the matching boson plus the suffix "ino". So, for example, the supersymmetric partner of the electron is called selectron, the partner of the top quark is stop squark and that of the Higgs boson is Higgsino. The discovery of supersymmetric partners in the LHC would be the resounding confirmation of the supersymmetry theory.

There are many reasons why we believe this might happen. The problem of naturalness, or hierarchy, requires the existence of new particles, presumably visible in the LHC, that explain why the energy scale that characterises the standard model (100 GeV) resists the pressure of enormous corrections according to which it would be far higher. The particles envisaged by supersymmetry would provide a particularly convincing explanation.

Considered as a whole, supersymmetry is an internally coherent and technically very sound theory which, in principle, allows the behaviour of the laws of nature to be extrapolated up to the Planck scale (10^{19} GeV).

The solution to some of the problems that require new physics beyond the standard model, such as the prevalence of matter



b.
Simulation of the production of supersymmetric particles in the LHC, as would be seen by one of the detectors (ATLAS). The lines represent the tracks left in the detector by the particles produced in the event, especially those derived from the immediate disintegration of supersymmetric particles.

over antimatter in the known universe or the origin of the mass of neutrinos, may lie in those energies, not distant from a unified theory of unknown forces. Furthermore, the predictions of supersymmetry correspond perfectly with those of the theories of the grand unification, according to which at least three of the four fundamental forces of nature (electromagnetic, weak and strong force) might simply be different aspects of a single unified force. This latter idea is particularly intriguing not only for its elegance and the deep understanding it fosters, again, in terms of symmetry, but also because it allows us to understand in a single stroke the quantitative characteristics of the forces between the particles described by the standard model, and it is hard to imagine that such a result is fortuitous. Moreover, as already stated, it is fully confirmed by the theory of supersymmetry, in which the intensity of the three interactions according to the standard model can be extrapolated to precisely the same value at the energy of the grand unification scale, i.e., in the region of 10^{16} GeV, another result that is difficult to ignore. Lastly, one aspect of supersymmetry that is much appreciated is the possibility of explaining the nature of dark matter (see p. 25, ed.). The experimental coherence of the theory would in fact result in the stability of one of the supersymmetric partners, which in that case would pervade our universe and could indeed constitute its dark matter.
Thus, there are clearly many convincing arguments to support the theory of supersymmetry. Not surprisingly, after the discovery of the Higgs boson, supersymmetry has ended up at the top of the list of particle physicists' "wanted" items. It must be said that during the LHC's first run (from 2008 to 2013) no supersymmetric particles were caught, and no other candidates emerged that could solve the problem of naturalness. This has led some theorists to question the validity of naturalness as the basis for believing that new particles will be discovered in the LHC. Although such considerations are premature, it is already clear that, were the argument for naturalness to collapse, we would find ourselves faced with a paradox, an explanation for which would become the central theme of our research. Solving this would involve a radical change of paradigm, for example, the use of anthropic considerations rendered possible by the multiverse hypothesis supported by some theoretical physicists (according to whom, ours is just one of the many possible parallel universes).
Nonetheless, the theory of supersymmetry can still have an important role. It may, in fact, allow us to confirm the unification of forces and explain the origin of dark matter. It would still be compatible with other convincing ideas about physics that go beyond the standard model, such as those regarding the origin of masses of neutrinos. And, if the theory of dark matter and unification are confirmed, it could lead in the direction of possible signals in future accelerators.

Biography
Andrea Romanino is full professor at the International School for Advanced Studies in Trieste (SISSA). He has conducted research at the Scuola Normale Superiore in Pisa, Oxford University, CERN in Geneva and FermiLab in Chicago.

Web links

http://particleadventure.org/supersymmetry.html

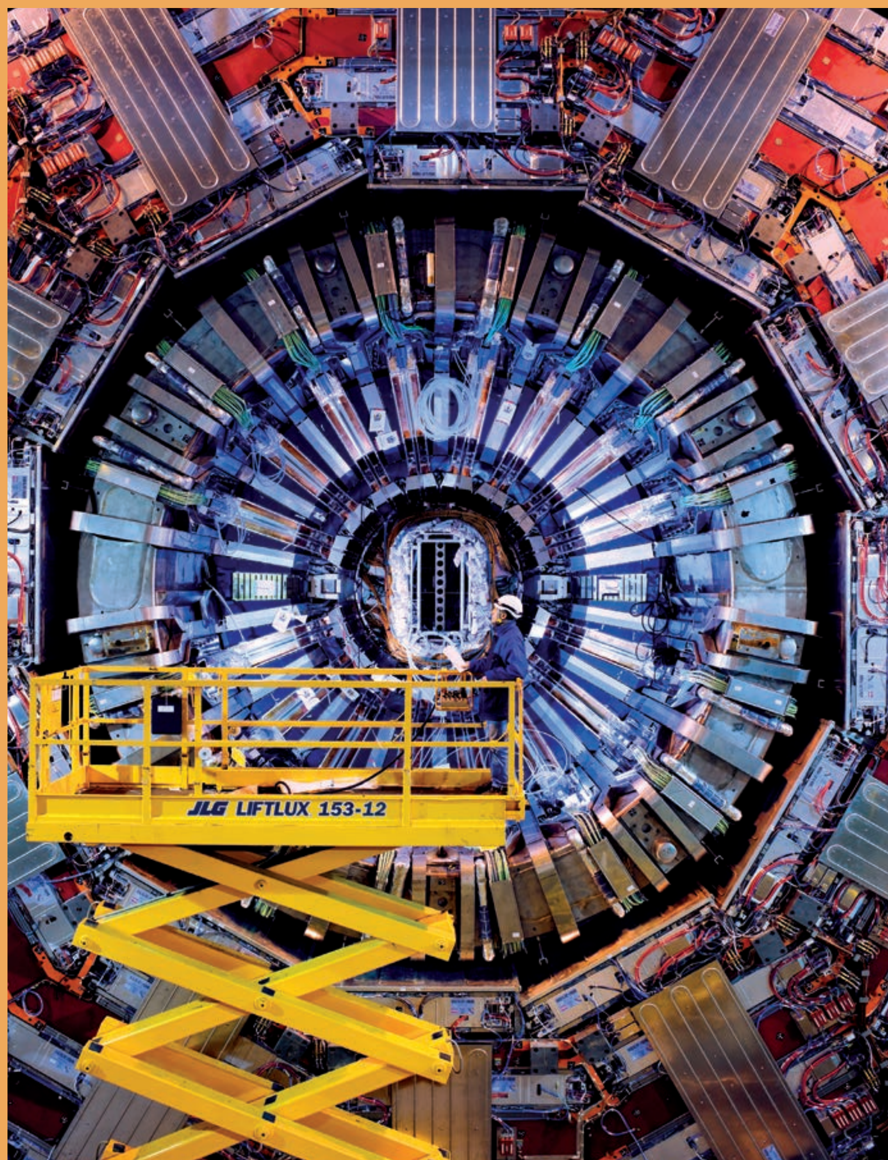
http://home.web.cern.ch/about/physics/supersymmetry

Desperately seeking SUSY

LHC in search of supersymmetry

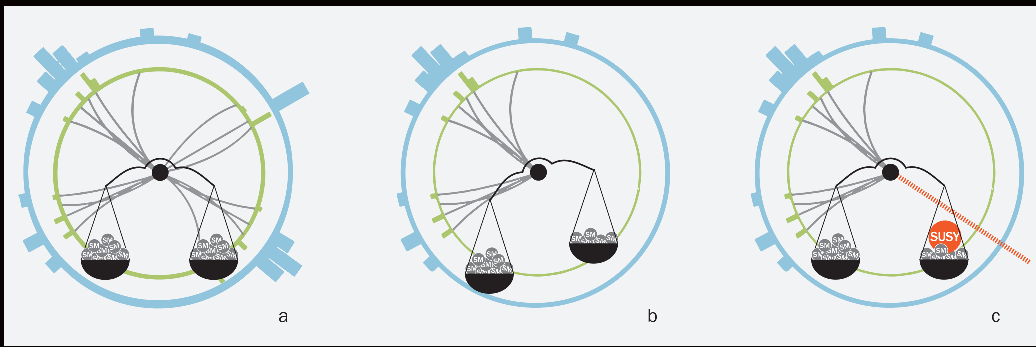
by Daniele Del Re

Physicists have an authentic passion for conservation laws. Not only in measuring the parameters of the standard model, but also in their search for the Higgs boson, they set strict limits to preserve the momentum and energy measured for the particles produced in a proton-proton collision, like those which take place in the LHC. However, when they start looking for something new or unexpected, their approach changes. In fact, it is precisely the apparent non-conservation of these fundamental quantities that makes it possible to identify events not predicted by the standard theory. If the collision of two protons in the LHC also produces supersymmetric particles, these decay and produce both standard particles as well as stable supersymmetric particles at the end of the cascade. These only interact weakly with matter and therefore cannot be measured. But the simultaneous presence of particles that are identifiable and others that are not creates an "imbalance" that can be measured (see "in depth" on page 17).
The search for supersymmetry in the ATLAS and CMS experiments is at a very advanced stage. There are tens of analyses studying the products of proton-proton collisions. Depending on the model of supersymmetry being tested, scientists are looking for different types of events, such as the presence of top or bottom quarks or of the Higgs boson. Unfortunately, in the data acquired so far by the detectors there is no trace of supersymmetry. Even without producing any concrete signals, these tests have allowed physicists to set limits for the mass of supersymmetric particles, although there are regions that have yet to be excluded. As new data are collected, the excluded regions will no doubt increase, unless supersymmetric particles are at last discovered. There are scenarios in which it would be more difficult to observe supersymmetric particles. For example, nature could have organised supersymmetric particles with specific combinations of masses, which would make it more difficult to observe the products of their decay. The fact that supersymmetry has not yet been observed has allowed us to exclude some of



a.
The CMS detector, at CERN Geneva, which together with ATLAS is searching for supersymmetry signals.

Scales for weighing SUSY



1.
Schematic illustrations of the tracks (in grey) and of the energy deposits (in blue) recorded by the LHC experiments. The superimposed balance scale represents (a) the energy balance of the event involving particles of the standard model only, (b) the imbalance if unobservable supersymmetric particles were present, and (c) the estimate of the energy of the supersymmetric particle that can be obtained assuming that the event was in effect balanced.

Let us imagine a particle detector like a balance scale. The particles of the standard model are all "visible" on the plates of the scale, because they interact with the detectors. Some of the supersymmetric particles, instead, interact very weakly and therefore cannot be seen. Now suppose we only put the particles of the standard model on the two plates. That way we can see whether the two plates with the same weight are actually in equilibrium: this is what takes place with standard measurements. However, if there is also a supersymmetric particle, even though we cannot see it directly, we can deduce its presence from the fact that the two plates are not balanced (see fig. 1b).
The LHC's particle detectors do not actually weigh the particles, but measure their momentum and can verify whether the sum of the momenta of the particles produced in a collision is balanced (this is no ordinary sum, but a vectorial sum, which considers the directions of the tracks). The three drawings in fig. 1 are simplified illustrations of the events that take place in the LHC detectors. The event on the left (a) represents a symmetric event typical of standard physics. In this case, the momenta of the particles are balanced: by dividing the detector into two hemispheres, the sum of the energy deposits in the calorimeters or of the momenta of the charged tracks between the two hemispheres is always balanced. With new physics particles, these carry a part of the momentum, but it cannot be measured if they interact weakly. The momentum carried by the supersymmetric particles is represented by the dotted line in the figure on the right (c). The event is thus imbalanced and, as shown in (b), there is only activity in one hemisphere of the detector. Therefore the presence of a notable imbalance unequivocally signals the presence of new physics. Clearly, this method only works well if the supersymmetric particle carries a significant momentum.

the theory's more favoured scenarios, but not supersymmetry as a whole. For example, the hypothesis that considers dark matter to be made up of supersymmetric particles is still perfectly plausible (see p. 25, ed.). Some searches for dark matter in the LHC look for very simple events. For example, in a proton-proton collision, scientists search for the presence of a single collimated jet of high-energy particles (a collision in which all the tracks illustrated in fig. 1b are very close to one another, forming a type of cone) or of a single photon or of a Z boson. Moreover, as explained above, the event has to be highly imbalanced. These searches have not produced any positive results yet either. The second phase of data collection at the LHC, with proton-proton collisions at 13-14 TeV, has just started. This new data-taking run should be better equipped to probe the theory of supersymmetry for two reasons. First, the collision energy will be almost doubled compared to the data previously acquired, making it possible to more effectively produce any supersymmetric particles with higher mass. This will open the way for studying previously unexplored phenomena.
What is more, the number of collisions recorded in the coming years will increase tenfold. Since the sensitivity of the searches increases as more collisions are analysed, it will be possible to highlight small excesses due to supersymmetry. Thus, the next few years will be very important for research into supersymmetry and new physics, and the LHC will be able to make a decisive contribution, in parallel with experiments in space and those directly searching for dark matter.

Biography
Daniele del Re is a university researcher at the Physics Department of the "La Sapienza" University of Rome. He has been working on the CMS experiment since 2006. He has had various roles in the experiment and is currently coordinator of the group looking for new physics with exotic channels.

Web links

http://cms.web.cern.ch/

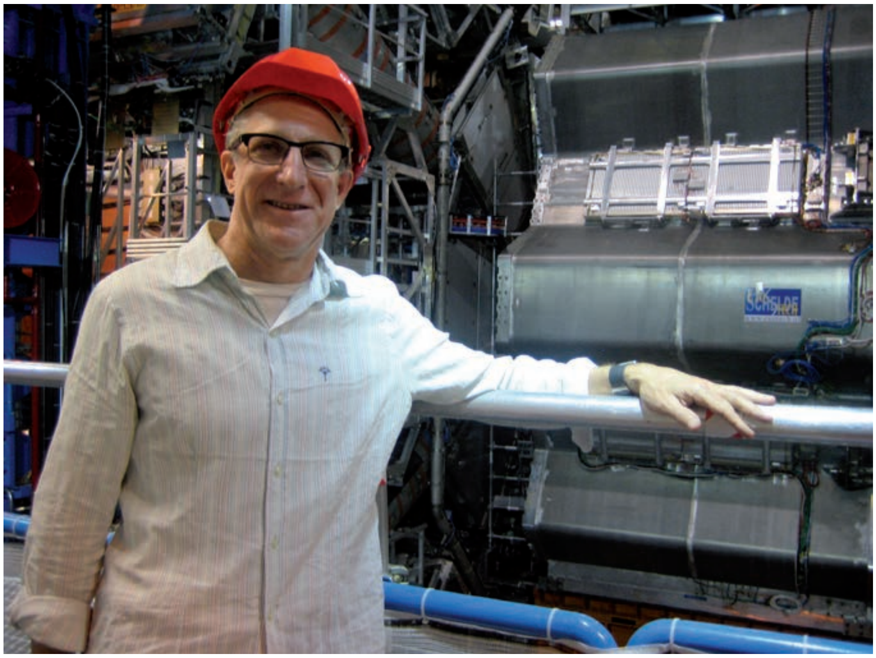
http://atlas.web.cern.ch/

[as] with other eyes

Particle fever.

by Mark Levinson

director of the film Particle fever



a.
Film director Mark Levinson in front of the ATLAS experiment at CERN.

People often ask me for advice about getting into the film industry. I tell them, the good news is, you don't need to go to film school. The bad news – I earned a PhD in theoretical physics. In some sense, it was perhaps the longest pre-production preparation in film history for making *Particle Fever*.
Although the jump from physics to film may seem like an enormous, discontinuous quantum leap, the transition actually felt remarkably organic. What entranced me about physics was the profound beauty and elegance of the theories, and the magic and mystery in the fact that abstract symbols, devised by humans, encoded deep truths about the universe. I made the transition to film when I recognized that it was an alternate avenue for representing and exploring the world that also seemed mysterious and magical.
In the film world, I worked in the narrative fiction format. For many years, I harbored the hope that I would find a project that could weave together the two seemingly disparate strands of my life and convey the excitement of physics in a dramatic way. I think science has rarely been depicted well in fiction films. So I began to think about various scenarios that might form the basis for a dramatic film. And then, through some potential funders for a fiction script I had written, I heard about this physicist, David Kaplan, who wanted to make a documentary about the start-up of the Large Hadron Collider.
David was a particle theorist, actively working in the field, and interacting with people on a daily basis who had great stakes in the LHC – some of them had been waiting for thirty years for an experiment like the LHC that could finally tell them if any of their theories were correct. It was a unique moment in the history of science, when something was going to turn on that would definitely provide answers to

b.
Showing of the film *Particle Fever* at CERN in November 2014. The director and all the "actors", including Fabiola Gianotti (third from left), were present.

some of the deepest questions about how the universe works. And it was immediately clear to me that it could provide the perfect combination of both a profound scientific discovery and a dramatic human story.
When I met David, I told him that I wasn't interested in making a conventional "science" documentary that would try to explain everything. But if we could make a human, character-based story that allowed me to use the narrative storytelling tools I'd developed, that would be tremendously appealing. And that's exactly what David wanted to do as well.
Of course, there were many challenges to actually making the film. First, there were 10,000 people involved in the experiment. We always knew we wanted it to be character-based, but who should we choose to follow? People were also scattered all over the globe. How, on a rather limited budget, could we cover people all around the world? As a story about real scientific discovery, we also constantly had to decide when and where something significant might occur. And most pressing of all, how long should we continue filming? What if there was no definitive discovery?
David and I met at the end of 2007 and I really started working on the film, essentially full-time, at the beginning of 2008. I was constantly thinking about possible endpoints, something that could be a satisfying end to the film. We actually did not think they would discover the Higgs while we were filming. Almost all the physicists said that it would be such a rare event and it would take the experimentalists years to really understand their detectors. And then, as we were trying to wrap up the film with just tentative results, the big announcement came on July 4, 2012. The discovery of the Higgs became the definitive, fantastic end for the film.
In constructing the film, the biggest challenge was certainly making it accessible to a non-specialist audience. We wanted the film to be intelligible to a general audience, while at the same time remaining authentic. The key became knowing what to leave out. We didn't aim for a film that explained everything. But we wanted to convey the excitement, and truth, about real scientific discovery.
One of the ways I hoped to connect to a more general audience was by emphasizing the parallels between frontier level scientific research and art. Many of our characters felt this connection. Near the end of the film, Savas Dimopoulos asks, "Why do we do science? Why do we do art? It is the things that are not directly necessary for survival that make us human".
Fabiola Gianotti provides a quote from Dante's *Divine Comedy*: "*fatti non foste a viver come bruti, ma per seguir virtute e canoscenza* (you were not made to live as brutes, but to follow virtue and knowledge)". Science and knowledge are very important, like art is very important. It's a need of mankind. In the end, that's what I hope people take from *Particle Fever*.

A good push

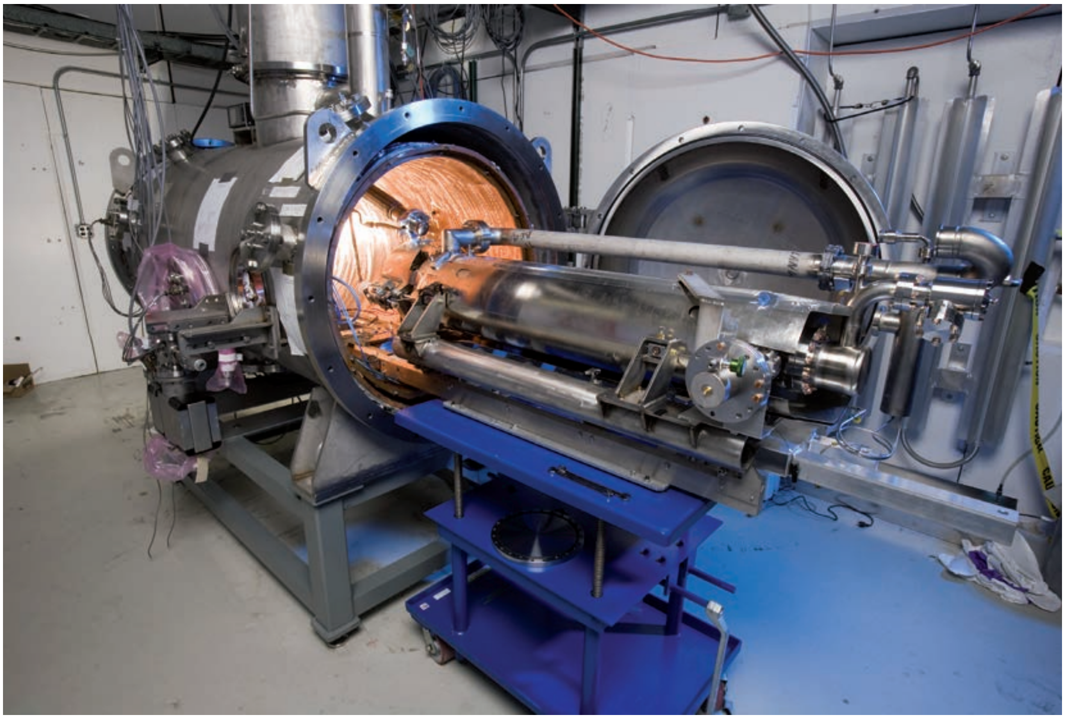
Accelerators for the new physics

by Lucio Rossi

Starting from the first machines, constructed in the 1930s by John Cockcroft and Ernest Walton in England and by Ernest Lawrence in the USA, and then the ADA collider (Frascati, early 1960s), accelerators have accompanied the progress of nuclear and particle physics right up to the discovery of the Higgs boson. They have been the main tool used by physicists to chase the infinitely tiny, arriving at measurements as small as 10^{-20} metres with the LHC at CERN in Geneva, with a sensitivity a couple of orders of magnitude higher than the previous accelerator, the LEP (the Large Electron-Positron Collider). For their capacity to concentrate energy in the smallest of spaces, accelerators are also time machines: in the LHC we investigate what the universe was like less than one picosecond (10^{-12} seconds) after the Big Bang.
The accelerated particles are generally electrons or protons, although they may also be different types of ions, ranging from hydrogen to completely ionised uranium and even highly unstable radioactive ions. But, for the physics of high energies, it is above all electrons, protons and muons (along with their antiparticles) that are accelerated, although experiments with muons are still underway.
Accelerators have developed along two main lines: circular machines (cyclotrons and synchrotrons) and linear machines (LINAC). In both the cases energy is imparted to the particles by means of radio frequency (RF) resonating cavities, in which there are electromagnetic waves.
Magnets are required to guide the particle beams (for example to keep them in a circular orbit in the synchrotrons) and to focus them – by magnetic lenses – to prevent them from impacting the walls of the vacuum chamber in which they travel. The main components of a circular accelerator are shown in fig. a, in which the beam is made to circulate many times through the radio frequency cavities, which therefore do not need to have high power or be very long. The magnetic part, on the other hand, is predominant, since both the magnetic field and the accelerator radius must be increased to obtain high energies. Linear accelerators instead consist of a series of radio frequency cavities, through each of which the accelerated particles pass only once: high radio-frequency voltages (tens of millions of volts) are important in order to limit the size of the machine. In LINACs the main purpose of the magnets is to keep the beam focused.
The Large Hadron Collider (LHC) with its 27 km circumference, 1700 huge 7 and 8 tesla superconducting magnets (by way of comparison, a magnetic resonance machine produces a magnetic field of one tesla and the Earth's magnetic field,

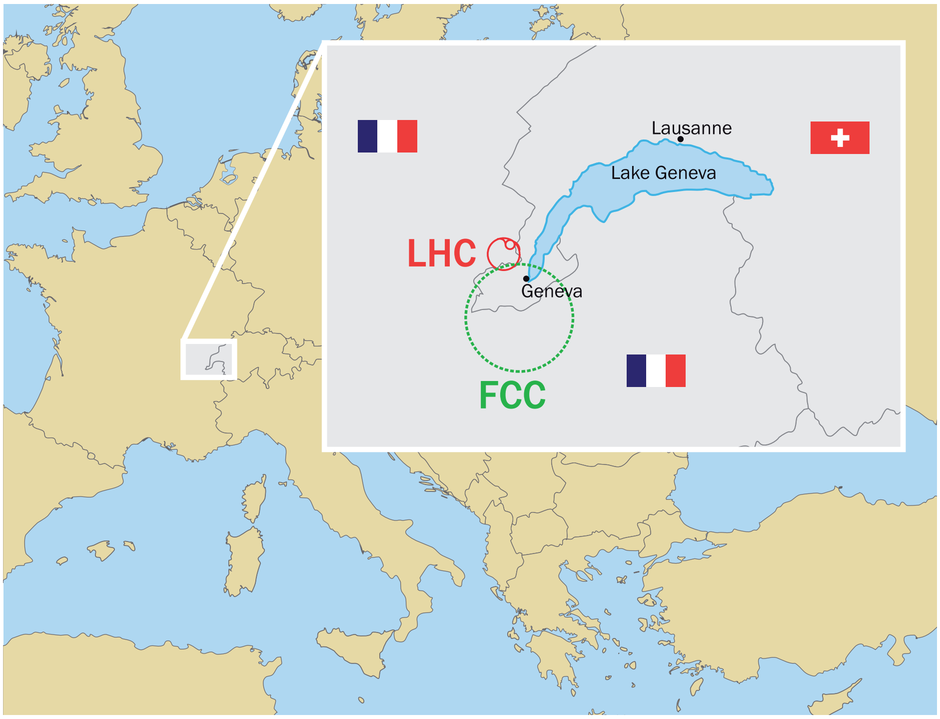
a.
The main components of an LHC-type particle accelerator: radio-frequency accelerating cavities (a), bi-polar magnets (b) to guide the beam and quadrupole magnets (c) to focus it. The three particle detectors (d) are also shown

which directs the needle of a compass, is a few hundred thousandths of a tesla) and maximum energy of 14 TeV is the culmination of 40 years of work on developing superconducting colliders, and took more than 20 years to design and build.
The first step to move beyond the limits of the LHC is already underway: the High Luminosity LHC (or HILUMI) project is developing new technologies for 11 and 12 tesla superconducting magnets using a more advanced superconducting material that is also much more complex and costly than the niobium-titanium (Nb-Ti) used in the LHC: niobium-3-tin (Nb3Sn). HILUMI has a limited number of magnets, around 50, and constitutes the ideal test bench for this technology. HILUMI also features a new type of superconducting radio frequency cavity, called a crab cavity, for rotating the beams and increasing their luminosity, i.e., the number of particle collisions produced by the accelerator in a unit of time.
The High Luminosity LHC will be able to measure the properties of the Higgs boson and any other new particles with greater precision. The machine is scheduled to come online in 2025. Its construction will cost around € 700 million for the components alone, and it is expected to run for 10-15 years.
A very different project, but which is also at the frontier of precision physics, is the ILC (International Linear Collider). The advantage of a linear collider with respect to a circular collider is that it can accelerate light charged particles like electrons and positrons, without these losing their energy when they pass through the magnets used to change their trajectory. The energy lost with the emission of radiation is very limited in the LINAC which makes it possible to accelerate light particles at higher energies.
Based on powerful superconducting cavities, with a voltage of 30 million volts (five times higher than the LHC cavities), the aim of the ILC will be to make electrons collide with positrons. In a first phase the energy at the centre of mass (i.e., the energy that is actually available) should be 0.5 TeV with the possibility of reaching 1 TeV in the second phase. The project, which follows on from the German Tesla project proposed in the mid ’90s, has made a lot of progress and is at an advanced stage of maturity, despite some notable technological challenges. The total cost stands at around € 10 billion and it is not expected to be ready until after 2030. Offsetting the advantage of having a technological precursor, the X-ray Fel (Free Electron Laser) project in Hamburg – a LINAC for lower energy electrons using the same radio frequency technologies –, the ILC project has two weaknesses: it is expensive, while not achieving the energies of the LHC even at maximum configuration, and, since it requires almost 50 km of high technology, its usefulness also critically depends on the attainable luminosity, which is much lower for LINACs than for circular accelerators. Another electron-positron linear collider project is CLIC (Compact Linear Collider). Based on a system of two accelerators, with very high frequency copper cavities and voltages of 100 million volts, it could, in principle, triple the efficiency of the ILC, thanks to its 3 TeV at the centre of mass and 50 km in length. Promoted by CERN, with a large international collaboration, it is less technologically advanced than the “rival” ILC project. Construction could start in 2020-2025, with startup between 2035 and 2040. Its weakness is its energy consumption of around 600 megawatts (there are no superconducting cavities or magnets), which is equivalent to the power generated by a medium-to-large electric power station.



b.
A niobium superconducting cavity for the ILC, enclosed in the helium cryogenic chamber, during its insertion into the test station at FermiLab, in Chicago (USA).

c.
Position of the 100 km FCC ring between Switzerland and France, in relation to the current LHC.

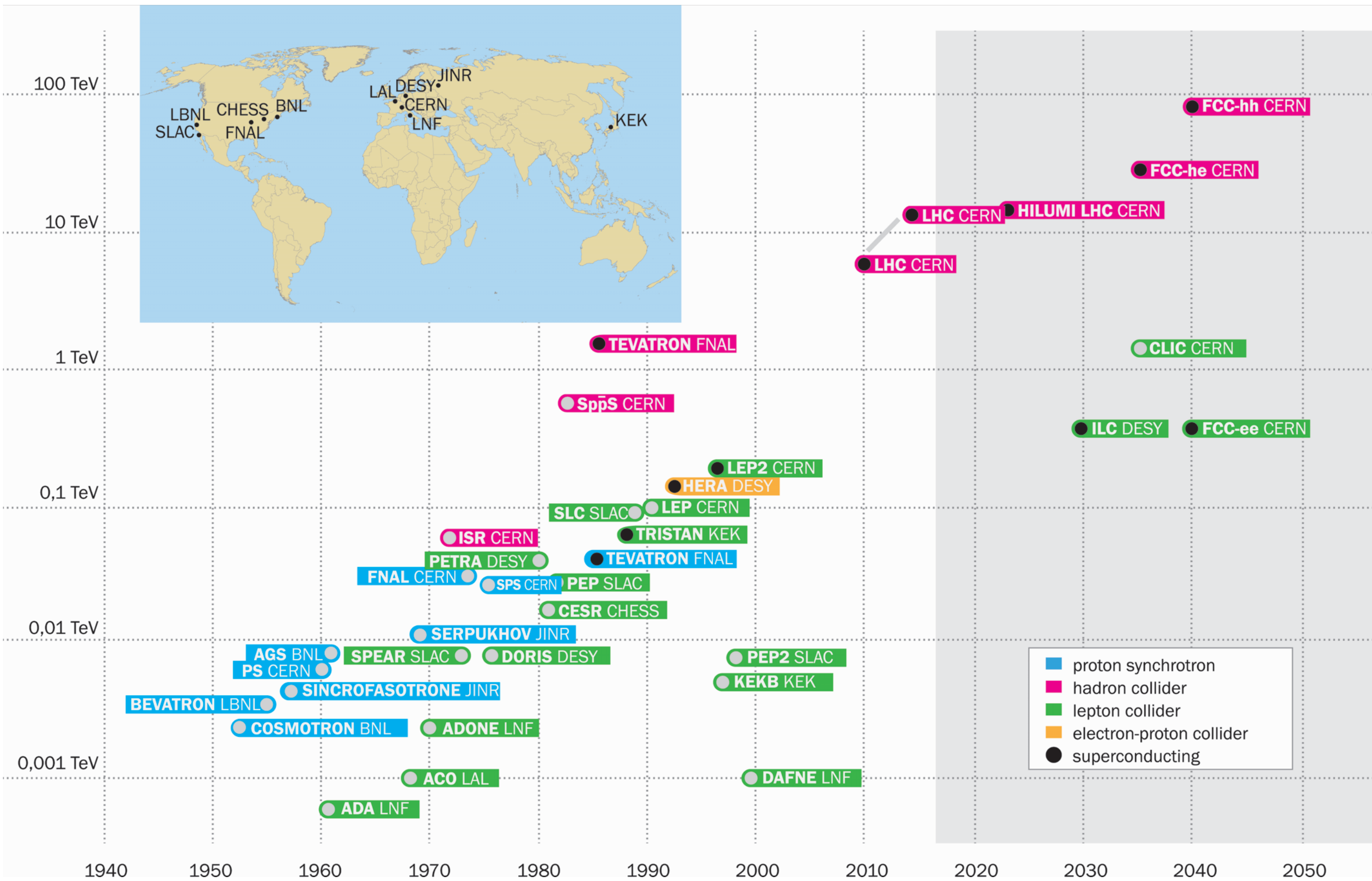


Moreover, there is no real “scale demonstrator”: a small prototype of the accelerator (even a few percent of the final accelerator) to prove that it works. However, if the LHC were to discover one or more particles with a mass between 0.5 TeV and 1.5 TeV, the ILC would not be able to “see them”, whereas the CLIC would. The cost of construction is comparable to that of the ILC (although the project is less “mature” and so the figures are less certain), but the operating costs would probably be much higher.

As far as circular accelerators are concerned, studies regarding the Muon Collider initiated by the USA in 2014 have run aground. All energy is therefore now being concentrated on the new FCC (Future Circular Collider) project proposed by CERN. Based on a 100 km underground ring to be constructed near Geneva, it would use all CERN’s existing infrastructure, as well as requiring a great deal more. The idea is to create an “all-inclusive” ring: the 100 TeV centre of mass hadron collider for proton-proton collisions (and heavy ions as in the LHC), FCC-hh could also follow a 350 GeV (0.35 TeV) centre of mass electron-positron collider FCC-ee. In the FCC it would therefore also be possible to obtain electron-proton and electron-ion collisions (FCC-he). The lepton collider, whose energy is limited by the enormous synchrotron radiation released by the electrons, could produce the luminosity required by particle physicists more rapidly and more surely than the ILC. The FCC-hh hadron collider, on the other hand, requires considerable technological investment, given that it is based on superconducting magnets similar to those that would be needed for the HILUMI, but even more powerful.

A value of 15-16 tesla, or even 20 tesla (although the latter is, for now, only a preliminary hypothesis) is required in order to reduce the machine’s radius or increase its energy. This work will entail an additional period of research and development besides that necessary for HILUMI. The FCC could be approved in around 2022-2025 and be ready to start in about 2040, although the lepton FCC-ee collider might be ready some years before then, since no specific technological developments are required. The challenge is formidable but there is in principle no reason why 15-16 tesla should not be attainable using the niobium-3-tin magnets of the HILUMI project. On the other hand, the possibility of reaching and exceeding 20 tesla depends on the development of high-temperature superconducting materials which are currently very costly and not yet suitable for use in magnets for particle accelerators. As regards the physics of particle accelerators, FCC is a more “traditional and secure” option, including in terms of luminosity: everything that is learnt with HILUMI is immediately transferable to FCC-hh. The costs are not known, the study is only just starting, but the figure could stand at around € 15 billion. One advantage lies in the use of remarkable existing infrastructure, CERN and the LHC, another is that major new infrastructure (tunnels, cryogenics, etc) can be shared by the different proposed accelerators. An intermediate step on the road towards the FCC could be to double the energy of the LHC, a project proposed in 2010 under the name of High Energy LHC, using 16 and 20 tesla magnets to reach energies of 26 and 33 TeV, to be installed in place of the LHC in the same tunnel, thus reducing infrastructure costs to a minimum. Another stimulus to the challenge comes from China. A group of Chinese physicists plan to build an accelerator with a 50-70 km tunnel to the south of Shanghai. Their initial aim is to construct a circular lepton collider within a shorter time frame

(from 2030), similar to FCC-ee (in strong competition with the ILC that might be constructed in Japan). A subsequent phase (around 2040) envisages the construction of a "FCC-hh-like" accelerator, probably with energy of 60-80 TeV, in the tunnel. The critical time for a decision could be the renewal of the European Strategy for High Energy Physics, scheduled for 2018-2020. Meanwhile, new data collected by the experiments in the LHC will have provided information that is currently not available and we will know more about the technological evolution of new high-field magnets and high-gradient radio-frequency cavities. We will also have a better idea of the costs involved. The ILC could be the exception, as its future mainly appears to be linked to a decision of the Japanese government, which is expected within a year or two. Since China wants a super-accelerator and the machine that is "most ready" is the ILC, members of the scientific community are starting to wonder whether a Chinese ILC might be best.
In any case the "post-LHC" era is opening new scenarios that would have been unimaginable only a few years ago, truly accelerating our entry into the future.



d.
The evolution of accelerators in time. Note the impact of superconductivity. The dates for future accelerators are clearly all highly hypothetical.

Biography
Lucio Rossi has been a professor in Milan since 1992. Until 2001 he conducted research and projects in the field of superconductivity applied to accelerators and detectors. In 2001 he joined CERN, where he led the group involved in construction of the magnets for the LHC from 2001-07. He proposed the HILUMI project, for which he is project manager, and is among the proponents of the High Energy LHC and FCC projects.

Web links

http://tlep.web.cern.ch/

http://lpap.epfl.ch/page-54797-en.html

https://www.linearcollider.org/ILC

[as] reflexes

Magnets for the future.

by Eleonora Cossi

ASG Superconductors is an Italian company that boasts a history of cutting edge technology in the field of the conventional and superconducting magnets that goes back to the '50s. The Magnets Unit of the Ansaldo industrial group, which became ASG Superconductors in 2001, has produced magnets for the most important European laboratories and high-energy physics experiments, including the dipoles for the Elettra project in Trieste and Hera in Hamburg, the quadrupoles for the ESRF project in Grenoble and the bars and quadrupoles for the LEP accelerator at CERN. During the construction of the LHC "technicians" at ASG made 400 magnets to be used in the accelerator and detectors of the CMS and ATLAS experiments. Today the company is engaged in the production of the new superconducting magnets for the HILUMI project. "Engineers at ASG have been working at CERN's laboratories for about a year now, designing the magnets that will allow the LHC to reach the highest luminosity values. Meanwhile, engineers at our workshop are also contributing by transferring the construction methods necessary to develop the new accelerator", explained Vincenzo Giori, Managing Director of ASG Superconductors.

[as] Exactly which magnets is the company contributing to?

[Vincenzo Giori]: ASG is working on the design and construction of the quadrupole and dipole magnets. The former are responsible for the correct focusing of the beam during its orbits in the accelerator, the latter for defining the actual trajectory of the beam's orbit.

[as] What characterises these new magnets?

[Vincenzo Giori]: The distinctive characteristic of the magnets we're working on is the type of superconducting material used, niobium-3-tin (Nb3Sn), which has never been used in accelerator magnets before because it is a particularly complex component to develop. Unlike niobium-titanium (Nb-Ti), which is used more frequently, niobium-3-tin can withstand extremely high current densities, but has to be heat treated at 650°C, otherwise it is a poor conductor.

[as] There are promising applications for superconductivity in fields ranging from thermo-nuclear fusion to the optimisation of electricity networks and medicine. Which applications do you foresee for niobium-3-tin?

[Vincenzo Giori]: So far, niobium-3-tin is the only reliable material for producing magnetic fields of more than 20 tesla, which will have important implications for research into new medicines. Nevertheless, we need to drastically reduce the costs and make it much more practical to use if it is to be useful in other sectors.

a.
Vincenzo Giori, Managing Director of ASG Superconductors based in Genoa.

Behind the scenes of the universe

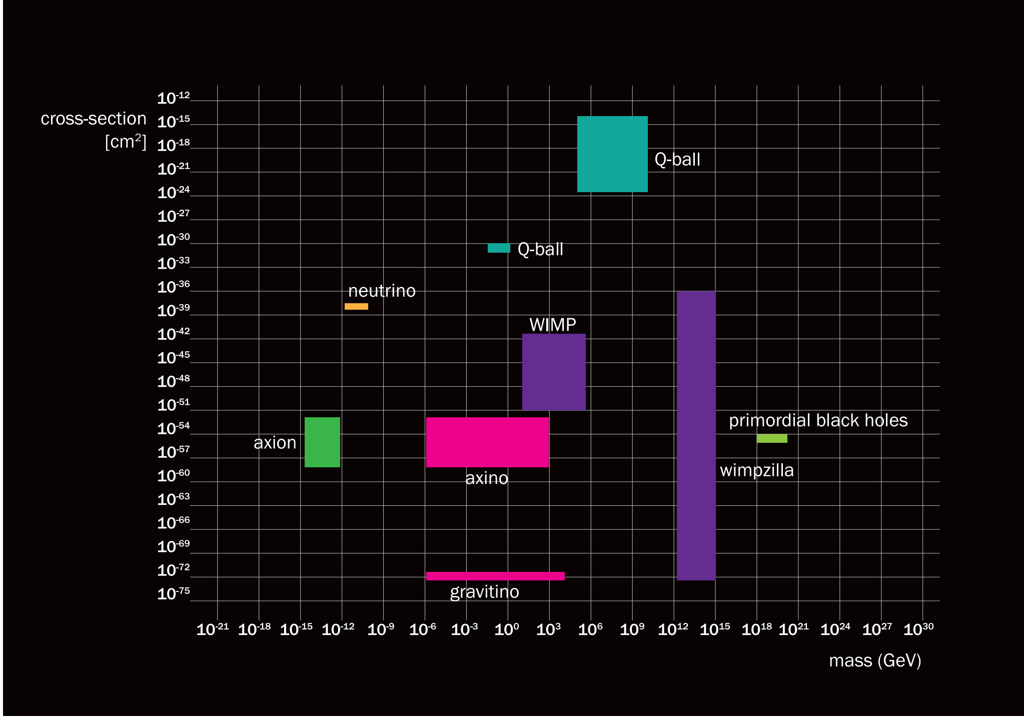
Hypotheses about dark matter

by Gianfranco Bertone

If you look at the sky from a dark enough place, the Milky Way looks like a band of dim light running across the firmament. The realisation that what James Joyce called "infinite lattiginous scintillating uncondensed milky way" is simply the disk of stars and gas of the galaxy we live in, as seen "from the inside", is a revelation that gives the sky a sense of perspective, providing depth to the otherwise two-dimensional vault of the heavens.
However, according to modern cosmology, in the galaxy we live in – the Milky Way – there is a lot more to see than what is visible to the naked eye. Not only is there more matter than even our most powerful telescopes would be able to observe, but, as we now know, that matter is not made of stars, planets, comets, asteroids or gas: it is something fundamentally different from any other substance that has ever been observed in our laboratories. It is called dark matter, because it neither emits nor absorbs light, but the name is especially appropriate for a substance whose nature is wrapped in mystery.
It took the scientific community a long time to come to this conclusion, but towards the end of the '70s, after decades of pioneering research, proof of the existence of dark matter was practically irrefutable. Added to the measurements that were available then, such as anomalies in the speed of rotation of stars and gas at huge distances from the galactic centres and the inexplicable speed of galaxies grouped together in big masses, we now also have what is called background cosmic radiation, discovered in 1964 by Arno Penzias and Robert Wilson and measured with extraordinary precision by satellites like NASA's WMAP in 2003, and recently by Planck, launched by the European Space Agency.
Just like an iceberg of which only the tip is visible, we know, thanks to the laws of physics, that the part above the surface, the universe with which we are familiar, represents only a small part, around 5% of all matter-energy. Identifying the nature of the remaining 22%, made up of dark matter, and of the 73% made up of dark energy (see p. 31, ed.), is one of the chief objectives of modern cosmology.
But how do you look for something you know nothing about? One of the most interesting ideas, and perhaps the one on which the scientific community is currently concentrating most of its attention, is that dark matter is composed of a new type of elementary particles, generically called WIMPs (Weakly Interacting Massive Particles). WIMPs are interesting for several reasons: their existence is predicted by new theories of particle physics – such as supersymmetry – which try to explain and extend the standard model of particle physics; they might easily have

a.
The galaxy we live in, the Milky Way, is made up of a disk of stars and gas, which can be seen with the naked eye and looks like a ribbon of light in the sky, and a huge quantity of invisible matter, dark matter, which supports its structure.

been produced in the right quantity a few moments after the Big Bang; and could be discovered through a series of experiments that are ongoing or will be conducted in the near future.
Of these experiments, two of the biggest and potentially most interesting are ATLAS and CMS at the LHC, which discovered the Higgs boson in 2012. If dark matter is composed of WIMPs, it might be produced in collisions between protons accelerated to the highest energies and made to collide at the centre of the ATLAS and CMS experiments. All known particles leave a trace in the sensors of these two experiments, but not WIMPs, which disappear without leaving any trace, taking away part of the energy of the collision and thus manifesting their presence (see p. 16, ed.).
A second group of experiments, known as “direct detection”, look for the energy deposited by the dark matter particles that penetrate them and collide with the atomic nuclei inside them. However, there are two big problems with direct detection. The first is that the dark matter particles interact weakly and so the experiments have to be extremely sensitive and big enough to detect a statistically relevant number of events. The second is that very many “ordinary” particles, originating from deep space, penetrate the detector and so continually activate it. The experiments must be taken to underground laboratories, such as the Gran Sasso National Laboratory (in Italy), to shield these cosmic rays. Tens of experiments are currently underway. One of these is the DAMA experiment, which has observed for the first time an annual modulation in the number of events detected, a characteristic scientists expect to be consistent with the presence of dark matter, since during the Earth’s annual revolution around the Sun, a “wind” of dark matter particles blows and varies in strength according to the speed of the Earth with respect to the galaxy. A new generation experiment called Xenon1Ton will start this year and become the most sensitive in the world. Lastly, dark matter can be identified “indirectly”, by means of the particles – for example antimatter particles – produced by specific interactions called self-annihilation, in which two particles of dark matter collide, transforming their mass into energy. This approach has produced some interesting results, including the discovery of an excess of gamma rays, i.e., very high energy photons, observed by the Fermi space telescope towards the centre of the Galaxy, with characteristics that appear to signal the presence of dark matter, and the recent findings of AMS-02 (see p. 27, ed.).
In addition to WIMPs, many other solutions have been proposed to explain dark matter. Scientific articles are full of hypothetical particles such as axions, sterile neutrinos, mirror particles and many others with even more exotic names (see fig. b), a bit like the mythological and imaginary creatures of medieval bestiaries. Just as some of those "monsters" turned out to be versions, albeit distorted, of real animals, so modern science is searching among the particles imagined by theoretical physicists from all over the world for the ones that would explain the mystery of dark matter in the universe. And while we travel further on this journey suspended between the infinitely small and the infinitely big, every day we learn something more about the structure and evolution of the universe and our role in it.



b.
Theoretical physicists have proposed different possible candidates for the role of dark matter. Some of these are shown in the diagram, with the possible values of their mass plotted on the horizontal axis and the probability of interaction with ordinary matter, measured by the collision cross-section, plotted on the vertical axis. WIMPs are the most actively sought candidates.

Biography
Gianfranco Bertone is a professor at the University of Amsterdam, where he coordinates the activities of the Gravitation Astroparticle Physics Centre of Excellence. He is author of the book *Behind the Scenes of the Universe* and of the related *Dark Matter* app available on iTunes.

Web links

http://www.lngs.infn.it/en/dark-matter

http://www.perimeterinstitute.ca/videos/behind-scenes-universe-higgs-dark-matter

News from the space station

Antimatter and dark matter being studied by AMS

by Bruna Bertucci

a.
A selfie of an astronaut taken in orbit: at the top on the left the AMS-02 experiment is visible on the ISS structure.

"[…] we must regard it rather as an accident that the Earth (and presumably the whole solar system) contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about, these stars being built up mainly of positrons (positive electrons, ed.) and negative protons…" This is how Paul Dirac ended his speech when he received the Nobel Prize on 12 December 1933.
The conclusion of Dirac's speech ideally represents the starting point for the Alpha Magnetic Spectrometer (AMS-02) experiment, in which the INFN (Italian National Institute for Nuclear Physics) and ASI (Italian Space Agency) are taking part. The instrument, located on the ISS (International Space Station), is designed to pick up the weak signals of antimatter particles in the continual flux of cosmic rays passing through the space around the Earth.
Detecting these signals that belong to the infinitely small can supply the necessary clues to solve some of the unsolved mysteries about the infinitely big: the universe.
The first mystery concerns the predominance of "matter" particles around us (baryogenesis): where did the antimatter particles go? We have been led to believe that in the immediate aftermath of the Big Bang the universe was "symmetric", populated in equal measure by the elementary particles of matter and antimatter. Their natural and violent annihilation apparently

resulted in the disappearance of the entire population of antiparticles and the universe therefore evolved starting from the particles of matter – one in a billion – that survived the annihilation. No theoretical justifications have so far been able to adequately explain the origin of this asymmetry. So finding antihelium nuclei, or the antinuclei of heavier elements, that cannot be produced naturally in a universe built of matter alone, would open up a new scenario in which antimatter had not disappeared, but was simply confined to regions of the universe distant from Earth.
The second mystery deals with the nature of the matter that makes up our universe. Only 5% of the mass-energy content of our universe is attributable to the ordinary matter we are made of, basically protons, neutrons, and electrons, while around 22% is made up of dark matter particles, new types of elementary particles that interact weakly with ordinary matter and are therefore “invisible” to telescopes sensitive to the light produced by the electromagnetic interactions of matter. But rare collisions of dark matter particles (that annihilate when they collide) can generate photons, particles and antiparticles of ordinary matter (electrons/positrons, protons/antiprotons), whose flux overlaps that of the cosmic rays. Although there are different theories and hypotheses about the nature of dark matter and there is a great deal of uncertainty about the expected number of collisions, in all the possible scenarios the fluxes of particles produced by the collisions of dark matter are several orders of size smaller than those of cosmic ray particles, mainly protons, helium nuclei and heavier elements with a small percentage (1%) of electrons. Fluxes of antiparticles, which are particularly weak in ordinary cosmic rays, offer the only hope of finding any sign of dark matter. Collisions of cosmic rays with the interstellar medium are expected to produce about one antiproton for every 10,000 protons and one positron for every 10 electrons: these fluxes are comparable with those of dark matter and thus constitute a “base” from which to fight on equal terms in the hunt for new phenomena.
In terms of experiments, the first challenge in searching for weak signals like antimatter particles is to intercept the cosmic rays before they have the possibility of interacting with the Earth’s atmosphere and generating a flux of antimatter particles that could falsify the measurement. That is why detectors used in this type of research are sent to the upper layers of the atmosphere using aerostatic balloons or sent into orbit on space satellites, such as Pamela or Fermi, or onboard the ISS, like AMS-02.
The second challenge is to gather a significant sample of particles. The expected number of antiparticles at the relevant energies in order to identify new phenomena is a few hundred events a year for exposed surfaces of about one square metre. However, owing to weight limits and the electric power needed to operate equipment in space, the size of the equipment cannot be increased at will. Therefore, the only alternative is to design equipment capable of ensuring years of highly efficient operation.
But the fundamental point is to succeed in identifying the rare antiparticles with

b.
The AMS-02 experiment at NASA’s Kennedy Space Center shortly before being placed inside the Endeavour’s payload bay.

precision: electrons and protons only differ from their antiparticles for the sign of the electric charge. The only way to separate particles and antiparticles is to use a magnetic field able to bend positive and negative particles in opposite directions. Positrons and protons both have the same positive electric charge value but there is only one positron for every 1000 protons. To separate these, and to separate the antiprotons from the more abundant electrons, we need to exploit the different ways in which the two types interact with matter.

The AMS-02 experiment was therefore designed as a magnetic spectrometer. At its heart it has a permanent magnet and a trace detector made up of around 6.4m2 of silicon micro-strip sensors arranged in nine different layers, capable of measuring the position of the particles that pass through the apparatus with an accuracy of 10 micrometres. The apparatus includes five other instruments that perform complementary and independent measurements to identify the particles passing through them with precision.

The techniques used and the complexity of the apparatus are comparable to those of the latest instruments used in particle accelerators, but have been adapted to work in a space environment. The AMS-02 has been operating continuously since May 2011 on-board the ISS, in orbit at a distance of some 400 km from the Earth, absorbing a total power of 2kW - less than a washing machine! Measuring 3 metres in width, 3 metres in length and 5 metres in height, and with an overall weight of around 7 tonnes, it is a giant in space, but is a small fraction of the experiments in the LHC.

The experiment is controlled at a distance, through the NASA satellite network, which allows scientists to communicate with the ISS and download data from its 300,000 channels of electronics. Physicists in the CERN control room and at its twin facility in Taiwan work in shifts to monitor the apparatus 24/7 and act in real time, adjusting the experiment's control parameters as necessary according to conditions on-board the station.

In the first 30 months of data taking, AMS-02 has collected signals from around 40 billion cosmic particles, more than all the experiments conducted in the course of the century since cosmic rays were first discovered. Among these particles, about 10 million electrons and around one million positrons have been identified, and used to measure the ratio of the number of positrons to the combined number of electrons and positrons, reaching a previously unexplored energy limit for these components of cosmic rays. This result confirms an excess of positrons with respect to the expected natural abundance in cosmic rays, as already observed by Pamela and in the first 18 months of operation of AMS-02, by extending the measured energy range and improving the degree of precision. This is of extreme importance in order to create an identikit of possible sources of antimatter. One of these sources might well be collisions of dark matter (see "in depth").

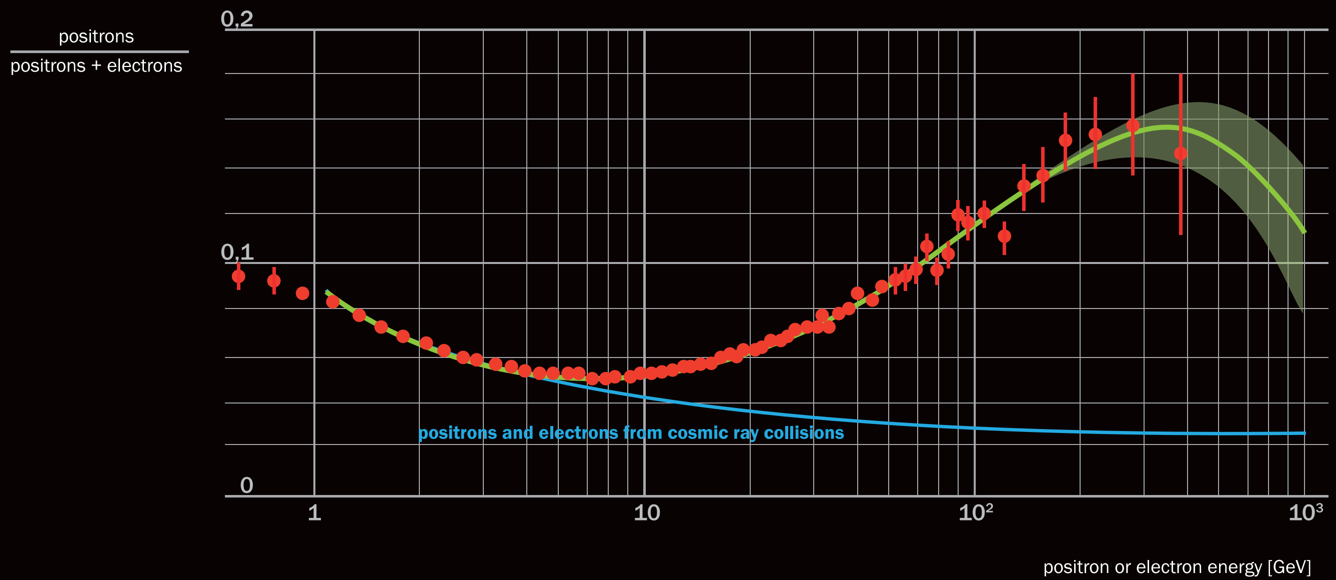
But is the increase in the fraction of positrons due to an additional source of positrons or to the "disappearance" of electrons?

The observation of the electron and positron fluxes separately characterises its trend as a function of energy with extreme

c.
The space shuttle Endeavour, which carried AMS-02 to the ISS in 2011, on the launching pad at Kennedy Space Center in Cape Canaveral, Florida.

Too many positrons

1.
Graph of the measurement performed by AMS-02 of the positron fraction in relation to the sum of electrons and positrons (red dots). The expected trend in cosmic rays is shown in blue. The green line best describes the experimental data.



As shown in fig. 1, the positron fraction observed by AMS-02 increases rapidly starting from an energy of 8 GeV, indicating the existence of a new source of this component of antimatter, with respect to the expected "standard" production of positrons in cosmic rays. The excess of the positron fraction is isotropic (that is, it has the same intensity regardless of the direction of measurement) within 3%, suggesting that this excess might not originate from specific directions.

A detailed analysis of the positron fraction as a function of energy shows this to increase gradually, excluding sudden variations, peaks or valleys, and the energy at which it ceases to increase has been measured to be around 275 GeV. Observations will continue over the coming years and be extended to even higher energies. This should improve our understanding of the nature of the phenomenon being observed and help us to describe its characteristics even more accurately.

precision. The results clearly indicate that there are no abrupt spectral variations in the electron flux, thus confirming that the behaviour of the positron component as a function of energy requires the presence of new phenomena for their production. These observations are consistent with the flux of positrons generated in collisions of dark matter particles (especially, neutralinos) with a mass on the order of 1 TeV. To determine whether the positron excess really does come from dark matter or from astrophysical sources, for example pulsars close to our planet, we need to measure the rate of decrease at which the positron fraction falls (see fig. 1) and then compare the effect that is observed with that measured in other components of antimatter, such as antiprotons.

On the other hand, the mission of AMS-02 has only just begun and the experiment will continue to collect data for the entire operational life of the ISS. It will carry on its observations and measurements for another decade or so, continuing to search for antimatter and observe or definitively exclude the presence of antihelium in our universe. At the same time, measurements to determine the composition and energy spectrum of ordinary cosmic rays will enable us to make progress in the study of their sources and the mechanisms whereby they pass through the galaxy, heliosphere and Earth's magnetosphere to reach us.

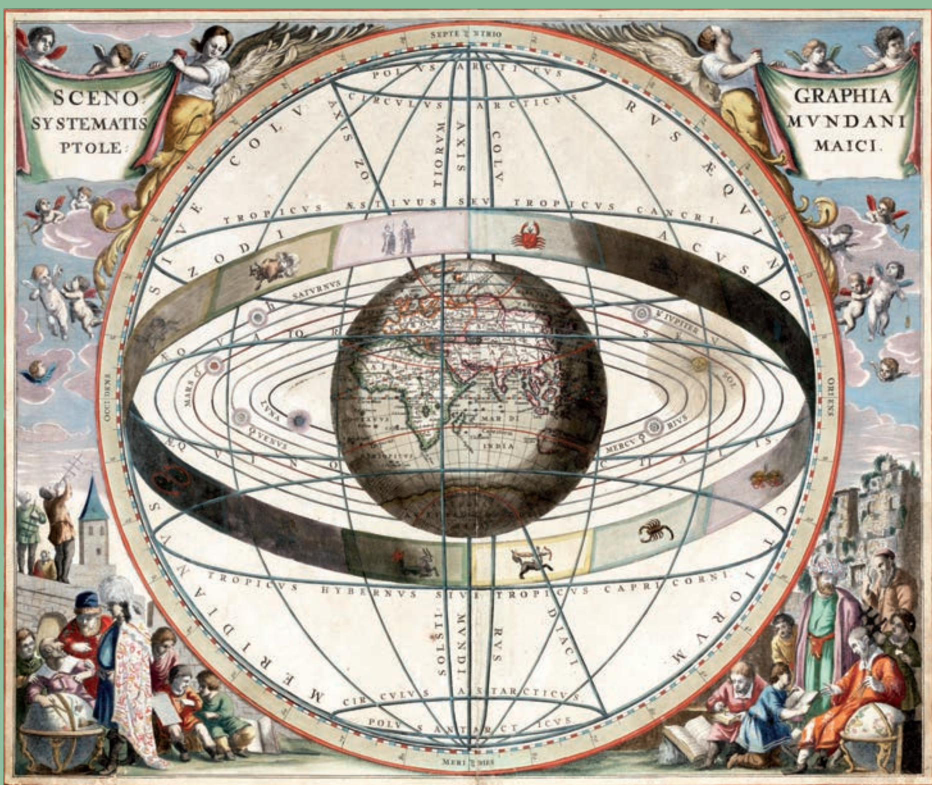
Biography
Bruna Bertucci is professor of physics at the University of Perugia. Her research initially addressed the field of elementary particles when she took part in the LEP experiments at CERN in the late '80s. Since the late '90s she has mainly focused on the experimental study of cosmic rays in space, first with the AMS-01 experiment and then with AMS-02, of which she is currently the Italian project manager..

Web links
www.ams02.org
http://www.asdc.asi.it/

… that moves the sun and other stars

Cosmological constant, dark energy and expansion of the universe

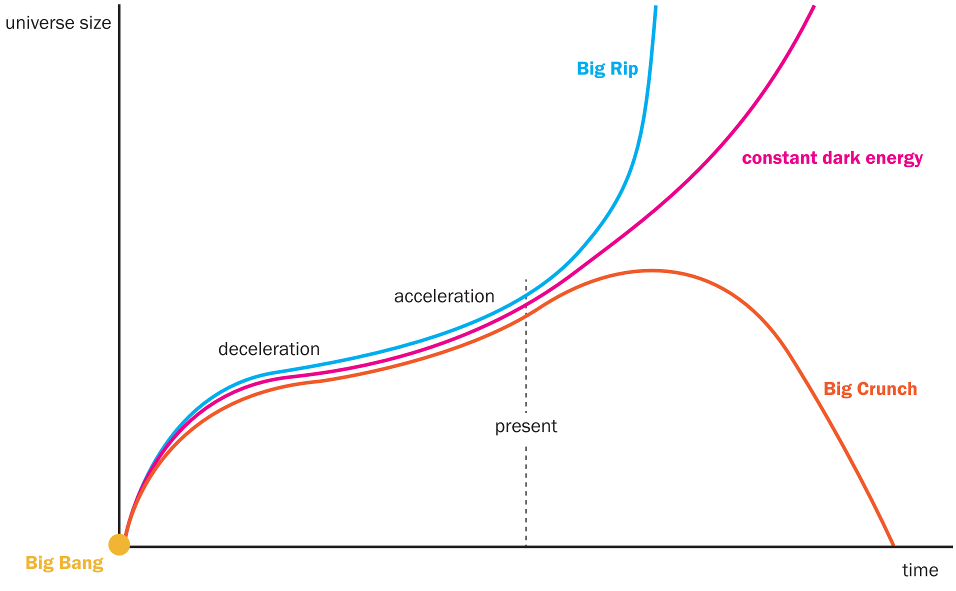
by Luca Amendola



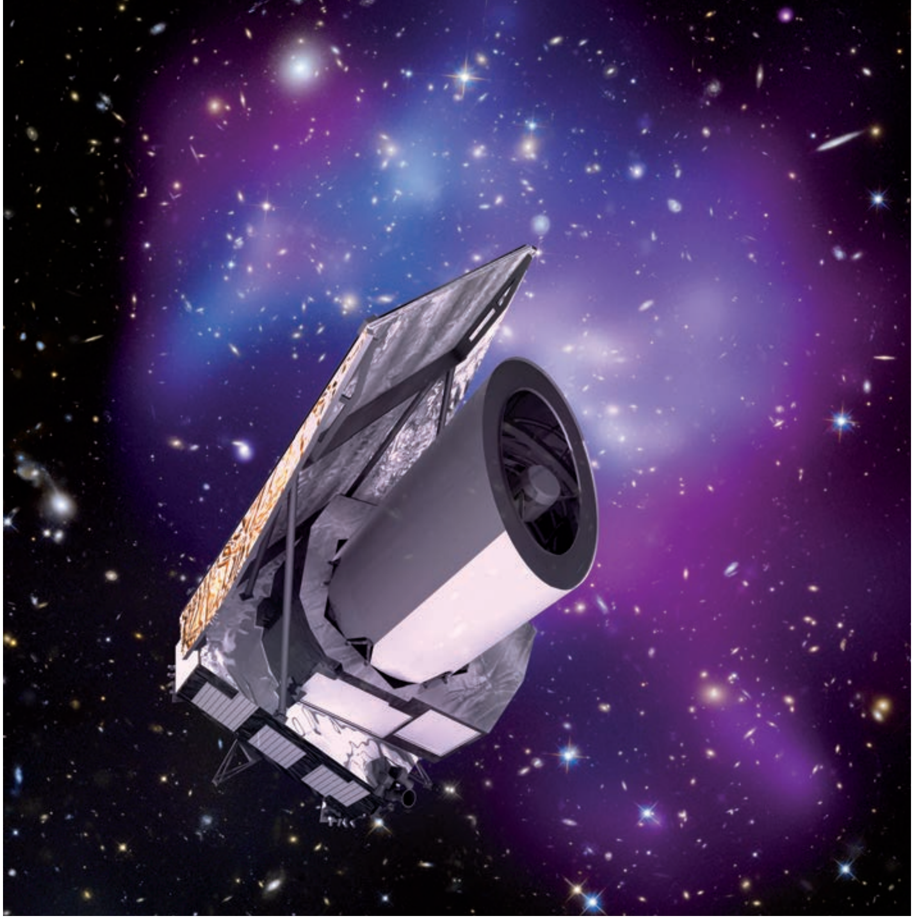
a.
The geocentric (or Ptolemaic) system described by Aristotle in De Caelo, a vision almost universally acknowledged for about two millennia by scholars who believed the cosmos was a static entity whose structure was eternal and motionless.

In the first pages of De Caelo, Aristotle, like many people before him, asks a very natural question: why don't the sky and the stars fall down on us? But because he was Aristotle and not just any distracted night owl, he immediately goes on to ask: why don't the stars move away from us? The idea of the universe as an evolving system thus began to emerge in the minds of great thinkers. But as Bohr once said, the opposite of a grand idea is another grand idea. For the next two millennia philosophers, theologists and the first modern scientists were almost unanimous in affirming that the cosmos was in actual fact a static entity with an eternal and motionless structure.
Einstein himself, in his earlier works on cosmology, did no better than Aristotle, almost repeating his same words: the sky is unchangeable, therefore the universe is static. But, being Einstein and no mere sophist, he soon understood that the only way to keep the universe static was to find a way of resisting the universal force of gravity. Since gravity is always attractive and acts on every particle, the concept of static distribution would mean that matter would collapse on itself. The solution conceived by Einstein in 1917, the famous cosmological constant, marked the start of a brilliant, multi-faceted career. A few years later, a number of astronomers, led by Edwin Hubble, discovered that the universe is expanding or, more correctly, that all the galaxies are moving and that motion is making them move further apart. This officially marked the beginning of modern cosmology, based on data rather than on speculations.
There was no need for the cosmological constant to explain the non-accelerated expansion that appeared to be observed at the time, and Einstein's idea remained dormant for several decades. Dormant but not forgotten because, even if not required, the cosmological constant is like the genie of the lamp: once out, it doesn't want to go back in.
According to quantum physics of fields the cosmological constant is an intrinsic

property of a vacuum and there is no evident reason why this should be null. On the contrary: calculations that can be done on a paper napkin show that this "vacuum energy" should be huge, huge enough to immediately make the entire universe "explode" or "collapse". Though somewhat absurd, such calculations do point to the fact that there is something deep down in the cosmological constant that we are completely missing.
The most spectacular come-back in the history of physics happened unexpectedly in 1998. Two groups of astronomers and physicists, led by Saul Perlmutter, Brian Schmidt and Adam Riess, published the results of a decade-long study. Just like Hubble fifty years earlier, the two groups had measured the velocity and distance of objects that were very far away, not galaxies this time, but type Ia supernovae, observable at distances a thousand times greater than Hubble supernovae. These supernovae explode when they reach a fixed threshold, called the Chandrasekhar mass. Their maximum luminosity is therefore relatively constant, regardless of the details of the explosion. By measuring the amount of light that reaches our telescopes, we can directly estimate the distance of the sources, because the amount of light collected depends inversely on the supernova's distance squared, with the appropriate correction needed for cosmic expansion. The conclusions reached by the two research groups shocked scientists: their data clearly showed a universe that was accelerating, inexplicable without a cosmological constant or something very similar. This meant new cosmic expansion, not something confined to the distant past, but taking place before our very eyes.
In actual fact, a whole host of diabolical details were undeservedly condensed into that adverb, "clearly". Before the cosmological constant could be demonstrated (and the Nobel Prize could be awarded to Perlmutter, Schmidt and Reiss, in 2011), the results had to be checked and all possible alternative explanations examined.
The cosmological constant, universally indicated with the symbol Λ, has many mysterious properties. The most important is that it is a form of energy that does not fade with distance, but remains constant. This is a consequence of another unusual characteristic, its strong negative pressure. According to the theory of general relativity, pressure exerts gravitational force just like mass. Because the resulting force is negative, it speeds the expansion up instead of slowing it down like ordinary matter and dark matter do. It therefore acts as a sort of antigravity, which is not very convenient for science fiction writers, because since it is absolutely homogeneous, it cannot be moulded at will to make antiplanets, antistars and antigravitation motors.
One immediate consequence of its value being independent of time is that the cosmological constant will continue to accelerate this expansion forever, even when the density of matter and radiation have fallen to imperceptible levels. Today it is estimated that the Λ constant is responsible for 73% of the universe's energy and that this percentage is set to rise over the next billions of years owing to the expansion of the universe.
The results of the supernovae were soon confirmed by many other observations, from those measuring cosmic microwave background radiation to deviations in the distribution of galaxies. Nonetheless, despite increasingly high levels of precision, the data obtained so far are not sufficient to establish once and for all whether or not the Λ constant is the only possible explanation.
To bridge the gap caused by this uncertainty, and in view of the fundamental problems that quantum physics associates with vacuum energy,



b.
The evolution of cosmic distances since the Big Bang. After the initial expansionary phase (not shown here) and subsequent slowing, the expansion of space started to accelerate due to the effect of dark energy. Of the various hypotheses about future trends, those illustrated here are the Big Crunch, where everything collapses back onto itself, and the Big Rip, where the universe expands so quickly that all physical structures, from stars to atoms, are ripped apart.



cosmologists have produced many other interesting hypotheses.
Just as the primordial expansion of the universe may have been triggered by a "particle" or rather a field, called inflaton, so its recent acceleration might be due instead to the cosmological constant, the hidden activity of a field/particle called dark energy or quintessence (back comes Aristotle!) or simply scalar field.
Like all fields, this extends and propagates throughout space and has its own dynamics. Like all particles, dark energy also has a mass, albeit so small that no accelerator can measure it directly: its wavelength is such that this particle is truly impalpable, distributed over distances equal to the entire universe.
Dark energy or quintessence resembles the cosmological constant, but it is not exactly constant and its density therefore varies slowly in time and can even fluctuate and increase slightly in space.
Lastly, there is another appealing possibility: the accelerating expansion of the universe might actually be due to a new dark force, capable of acting directly on matter, in the same way as gravity, electromagnetic fields or two fundamental nuclear forces. This "fifth force" is almost indistinguishable from gravity itself, so much so that it is even called modified gravity. A modified gravity could have innumerable consequences: the whole epic of the universe would have to be rewritten to account for a powerful new factor, going well beyond the mere cosmological constant.
The observational and theoretical efforts of cosmologists all centre around these hypotheses. One of the most ambitious projects is the ESA Euclid satellite mission, to which Italy is making an important contribution, scheduled to be launched in 2020. Euclid will be a cosmology telescope that, over five years, will catalogue the spectrums (and therefore the distance using redshift information) of 50 million galaxies and images of a further two billion, in order to create an accurate three dimensional cosmic map in a volume equal to a cube with each side measuring one billion light years. The galaxy distribution will be compared against those predicted by the various theories on dark energy and combined with all the data as they gradually become available. The result will be a high-precision measurement of all the main cosmological parameters, including the density of matter and dark energy, the mass of neutrinos, the primordial energy density fluctuation spectrum and the rate of expansion at different distances.
The hope is that we will at least be able to read the identity of the cosmological constant or dark energy or modified gravity in the folds of Euclid's map. The certainty is that Euclid and other similar experiments will provide us with a broader and deeper vision of our universe and help us to at last understand why the sky doesn't fall on our heads.

c.
Artistic image of the Euclid satellite.

Biography
Luca Amendola has been an astronomy researcher at the Italian Institute for Astrophysics (INAF, Rome Observatory) until 2009. He is currently professor of theoretical physics at the University of Heidelberg (Germany). He has spent periods doing research at FermiLab in Chicago, in France, Germany and Japan. He is the author of an educational book [Il Cielo Infinito (*The Infinite Sky*), Sperling].

Web links

http://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/

http://hubblesite.org/hubble_discoveries/dark_energy/de-what_is_dark_energy.php

http://sci.esa.int/euclid/42267-science/

Elusive mysteries

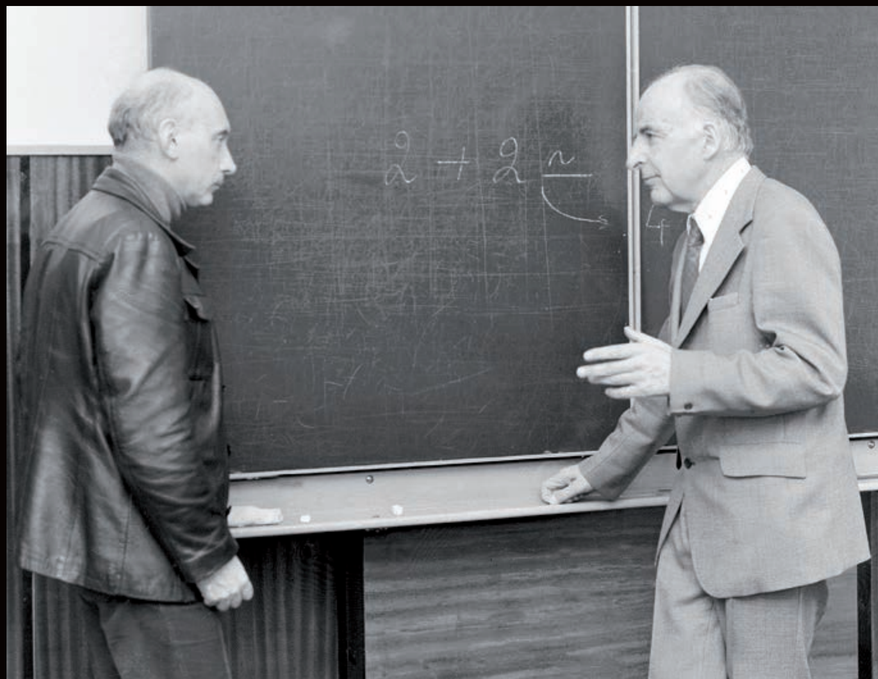
Mass and nature of neutrinos

by Carlo Giunti

a.
Clyde L. Cowan and Frederick Reines (left) with the detector they used to observe a neutrino for the first time at Hanford (Washington) in 1956.

Neutrinos are the most mysterious elementary particles known to us. They are among the fundamental particles of the standard model and their formulation has traditionally been based on their characteristics of interaction. However, 85 years after Wolfgang Pauli formulated his hypothesis and 59 years after the first experimental observation by Clyde L. Cowan and Frederick Reines (see “in depth”), we still do not know some of their fundamental properties: the value of their mass, their nature (whether they are of so-called Dirac or Majorana type) or their number (i.e., whether there are non-interacting, or sterile, neutrinos in addition to the three "active" neutrinos, the electron, muon and tau neutrino, known to interact with mattaer). There are also good reasons to believe that the unknown characteristics of neutrinos are linked to new physics beyond the standard model.
One quantity of fundamental importance for every particle, like for every body, is its mass, which determines its propagation and interaction properties. At present we know the value of the mass of all the particles in the standard model except neutrinos, the mass of which is so minute that until about 15 years ago we had no irrefutable proof that neutrinos were not massless. This proof came from the observation of neutrino oscillations, the mixing of neutrinos of different types (or flavours) which leads, for example, to the transformation of an electron neutrino into a muon neutrino. The phenomenon, proposed separately

Ghost stories

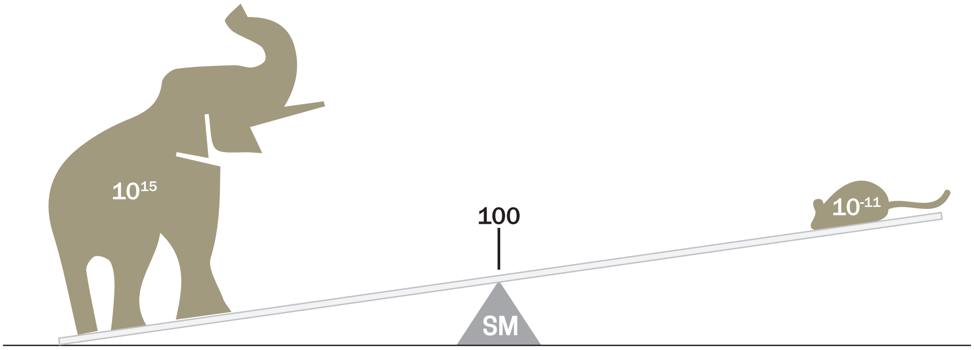


1.
Bruno Pontecorvo (right), one of the famous “Via Panisperna boys”, in conversation with his collaborator Samoil Bilenky. Pontecorvo hypothesised the existence of a second type of neutrino in 1960.

In 1930 Pauli proposed the existence of neutrinos to explain the fact that in nuclear decay due to the weak interaction (which is much slower than decay due to strong and electromagnetic interactions) electrons are emitted with a continuous spectrum of energy. This is only possible if there are at least three end products of the decay: the final nucleus, the electron and a neutrino, which was for a long time impossible to observe, because it is electrically neutral and only interacts weakly with matter (whereas charged particles like electrons leave traces in particle detectors due to ionisation of the atoms). Based on Pauli’s hypothesis, in 1934 Enrico Fermi proposed the theory of weak interactions according to which, however, neutrinos interact so weakly that it would be very difficult, if not impossible, to directly verify their existence. Fortunately, this pessimistic hypothesis was proved wrong by the fact that some sources produce huge fluxes of neutrinos: for example, a nuclear reactor typically produces around 1020 neutrinos a second per gigawatt of thermal energy and the Sun generates approximately 10 11 neutrinos a second per square centimetre (about the surface of a fingernail). Therefore, even if the majority of neutrinos pass through a detector as if it were transparent, given the enormous flux of neutrinos it is possible to observe some interactions that demonstrate the existence of these particles. This measurement was performed for the first time by Cowan and Reines in 1956 using a detector installed close to a nuclear reactor.
Their measurement finally proved the existence of an electron neutrino emitted together with an electron in the nuclear decay that occurs in a reactor. Meanwhile however, in 1937, the muon was discovered: a charged particle similar to an electron, but around 200 times heavier. In 1960 Bruno Pontecorvo proposed the existence of a second type of neutrino produced with a muon. This hypothesis was brilliantly confirmed in 1962 by the experiment conducted by Leon Lederman, Melvin Schwartz and Jack Steinberger, who demonstrated that neutrinos produced by weak interactions together with muons do not produce electrons when they interact with matter, as would electron neutrinos. They are therefore different particles, called muon neutrinos. Later, in 1975, a third charged lepton called the tau was discovered. The tau is the heavier brother of the electron and muon (around 17 times heavier than a muon) and the corresponding neutrino of the tau was observed in 2000. This completes the list of the three known neutrinos, which are active in the weak interaction processes that led to their discovery. There is still a possibility of finding other types of neutrinos, called sterile neutrinos, which are not associated with any charged particles in the standard model.

in the 1960s by Pontecorvo and Ziro Maki, Masami Nakagawa and Shoichi Sakata, depends on the distance the neutrino travels, its energy and the difference in mass between the neutrino types.
The measurement of these oscillations has enabled scientists to calculate the differences between the masses of the different neutrinos. These masses are minute; we know they have a mass, but it has not yet been possible to measure their absolute value. The experimental upper limit is around 250 thousand times smaller than the mass of an electron, which is the lightest particle of matter in the standard model apart from neutrinos. There must be an explanation for why neutrinos have a far smaller mass than the other particles in the standard model, but this cannot be derived in a natural way within the standard model, because it would mean setting an artificially low limit for the parameters of the standard model that determine the masses of the neutrinos. The smallness of the mass of neutrinos is, instead, thought to be due to their connection with the new physics, through their property of being either Majorana particles (i.e., particles which coincide with their own corresponding antiparticle), or Dirac particles like quarks and charged leptons (electrons,

muons and tau). Let us try to understand what that means.
In 1928 Paul Dirac proposed his relativistic quantum theory of fermions, like the electron, which for this reason are called Dirac particles. A fundamental characteristic of a Dirac particle is that the particle state (for example, the electron, which has a negative electric charge) always has a corresponding antiparticle state with the opposite electric charge (the positron in the case of the electron, which has a positive electric charge). Quarks and charged leptons (electrons, muons and taus) are Dirac particles, whereas neutrinos (that are neutral) may be Majorana particles, according to the theory developed in 1937 by Ettore Majorana. With Majorana particles, the state of the particle is the same as that of the antiparticle. This is only possible for neutral particles like neutrinos, while for charged particles the particle and antiparticle states are necessarily distinct since they have opposite electric charges.
Within the framework of the standard model, massive neutrinos can only be Dirac particles, because the Higgs mechanism that gives mass to particles can only do so for Dirac particles. For this reason it is extremely interesting to experimentally determine whether massive neutrinos are Majorana particles, because in this case the masses of neutrinos must be generated by a mechanism of new physics. Furthermore, if neutrinos are Majorana particles, the see-saw mechanism can be used to explain the smallness of their masses. This mechanism is based on the existence of new physics beyond the standard model at a very high energy scale, for example, the scale of the Grand Unification Theory (GUT) of the strong and electroweak forces, that is to say, on the order of 10^{15} -10^{16} GeV, much higher than the electroweak energy scale, which is on the order of 100 GeV, at which the standard model unification of the electromagnetic and weak forces takes place. According to the see-saw mechanism (see fig. b) the masses of neutrinos are proportional to the relationship between the square of the electroweak energy scale and the GUT energy scale, with a value of approximately one hundredth of an eV (10^{-2} eV), which is precisely the expected value of the masses of neutrinos.
Thus, if neutrinos are Majorana particles, their masses establish a link between the physics of the standard model and the new physics.
The experiments most sensitive to the small masses of Majorana neutrinos are those which try to measure an extremely rare process called neutrinoless double beta decay involving certain heavy nuclei, such as isotopes of germanium and tellurium, used in the GERDA and CUORE experiments at the INFN's Gran Sasso National Laboratory.



b.
Illustration of the see-saw mechanism: the greater (heavier) the energy scale of the physics beyond the standard model (100 GeV), represented by the elephant (for example, the energy scale of the Grand Unification equal to 10^{15} GeV) the smaller (lighter) the masses of Majorana neutrinos (represented by the mouse). According to the energy scale of the grand unification, the mass of a Majorana neutrino would be equal to 10^{-11} GeV.

New physics might even manifest itself through new, very light particles that, being neutral and not interacting with the weak force of the standard model, would appear to us as sterile neutrinos (a name coined by Pontecorvo in 1967). In this case the three active neutrinos, which "respond" to the weak interactions, through which they are produced and detected by physicists, can oscillate into sterile neutrinos, which elude experimental detection. This phenomenon might explain recent reports of failure to detect the measured flux of neutrinos generated in nuclear reactors and radioactive sources. The SOX experiment, using the BOREXINO detector at the Gran Sasso facility, will verify the validity of these findings in the next few years using radioactive neutrino sources. This measurement is clearly of the utmost importance in order to study the physics beyond the standard model, because a positive result would provide direct information about the existence of a new particle, the sterile neutrino, which does not belong to the standard model and whose minute mass must be generated by a new physics mechanism.

Research investigating the properties of neutrinos, which are unique among the particles of the standard model, provides a window onto the new physics that is difficult to open because neutrinos are so elusive. Nonetheless, given the resourcefulness and tenacity of physicists, we can afford to be optimistic that this will happen in the near future.

c.
A researcher at work on the CUORE experiment at the INFN's Gran Sasso Laboratory.

Biography

Carlo Giunti is a researcher at the Turin division of the INFN. He is mainly concerned with research into the physics of neutrinos, which is the subject of his book, *Fundamentals of Neutrino Physics and Astrophysics* (Oxford University Press, 2007).

Web links

http://www.nu.to.infn.it/

http://www.hep.anl.gov/ndk/hypertext/

http://pcbat1.mi.infn.it/~battist/cgi-bin/oscil/index.r

On the rocks

Neutrino telescopes under the ice

by Elisa Bernardini

a.
Artistic illustration of the Active Galactic Nucleus (AGN) of the ARP 220 Galaxy. Near the black hole and in the streams, the cosmic rays can be accelerated and neutrinos can be produced at extremely high energies.

Neutrinos are among the most elusive representatives of the world of elementary physics. With no electric charge and a minute mass, they are able to penetrate dense layers of matter without leaving any trace. Unaffected by the magnetic fields that permeate our galaxy and intergalactic space, they travel towards Earth following linear trajectories through which we are linked to their sources. Neutrinos might represent the only messengers for studying the spectacular events that produce extremely high-energy particles in the universe, which escape observation by traditional astronomy based only on the detection of electromagnetic waves. Would their discovery help us to solve puzzling questions like: how do stars explode? What happens in the proximity of a black hole? Where do the cosmic rays that reach Earth come from?
Neutrinos do, albeit rarely, interact with matter. And it is thanks to such collisions that we are able to observe them. The probability of neutrinos at energies of several million eVs interacting when they pass through Earth is in the order of one in a hundred billion. Even at higher energies, experiments to detect rare neutrino signals would take up a disproportionate amount of space, even more than the massive particle detectors at CERN in Geneva. Many neutrinos reach the Earth every second. Most of them, at lower energies of between a few thousand and a few million eV, come from the Sun and from stellar explosions, so called supernovae. At energies of up to about one PeV (10^{15} eV) neutrinos are produced in the interactions of the cosmic rays with the nuclei of the Earth's atmosphere and are called atmospheric. Collisions inside

Detectors in the abysses

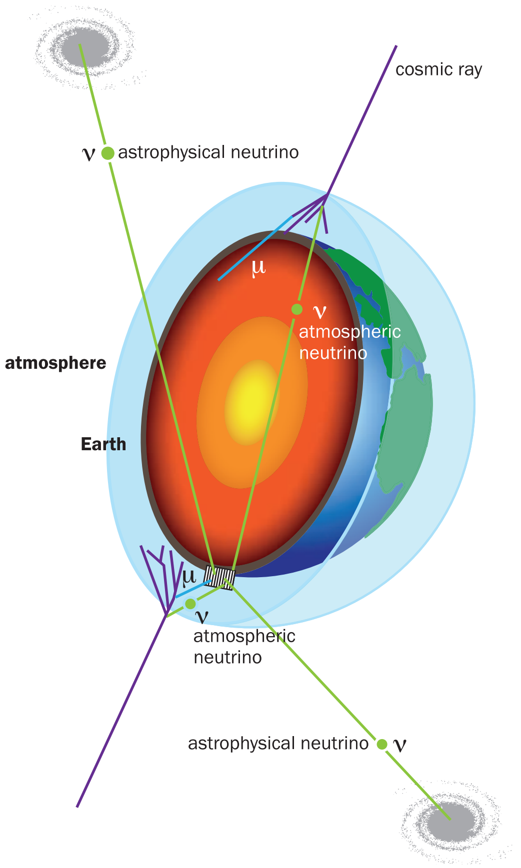
1.
The strings for the Baikal experiment are laid in the middle of winter, when the surface of the lake is frozen. Holes about 2 metres across are cut in the ice layer and the strings are installed with the help of pulleys. The different parts of the apparatus are connected to one another by watertight electrical and optical cables, capable of withstanding the pressure exerted by around 1500 metres of water that sits on top of the apparatus.

The idea of using huge natural volumes such as water or ice dates back to the ’60s. The rapid flashes of blue light, called Cherenkov light, emitted by the charged particles produced by the collision of a neutrino with a nucleus of matter, can be intercepted at great distances in a transparent medium. By recording the time of arrival and intensity of this radiation, scientists can trace the direction of the source and the energy of the neutrino. The first attempt to build an underwater optical detector was made in Hawaii in the ’70s, with the DUMAND experiment. Although it was cancelled, this was an important pioneering project and was tried again in the ’80s, this time more successfully, in lake Baikal in Siberia (Russia) (see fig. 1). The thick layer of ice facilitated installation and maintenance operations during the winter season, and 200 optical sensors were installed on 8 separate lines. Baikal was the first experiment to detect atmospheric neutrinos underwater. It is still running and work is now underway to create a kilometre-scale observatory (called the Gigaton Volume Detector). The open sea is also a transparent medium that is ideal for detecting neutrinos and the KM3NeT project, which recently deployed the first underwater structures off the coast of Capo Passero in Sicily, is looking to develop a neutrino telescope three times bigger than IceCube in the Northern Hemisphere.

Projects in the Antarctic ice have been no less pioneering. AMANDA, conducted towards the end of the ’80s, was the first experiment in the South Pole. Though based on the same kind of technology as the DUMAND experiment, different methods had to be devised to house it in the ice. The first sensors were installed at a maximum depth of one kilometre, where the Antarctic ice is still permeated with air bubbles that affect its transparency. The sensors therefore had to be installed at greater depths and it was only towards the end of the ’90s that scientists were able to demonstrate their operation under the ice. The baton was passed to IceCube in 2005.

astrophysical sources between accelerated protons and low-energy protons or photons can also produce high-energy neutrinos, although their numbers are several orders of magnitude smaller than in the previous cases. These are known as cosmic or astrophysical neutrinos.

IceCube, the biggest particle detector in the world, is distributed over one cubic kilometre of ice to detect neutrinos coming from the hidden depths of space. Researchers from more than 40 research centres in 12 countries have lowered 86 steel strings into the Antarctic ice sheet. Attached to the strings are 5160 optical sensors, a network of “electronic eyes” ready to capture the passage of a neutrino. At a depth of between 1450 and 2450 metres, in absolute darkness and silence, the weak light impulses induced by rare collisions



b.
The neutrinos detected by IceCube may come from astrophysical sources (cosmic or astrophysical neutrinos) or from interactions of cosmic rays with the atmosphere (atmospheric neutrinos). IceCube "suppresses" the source of atmospheric neutrinos coming from the Southern Hemisphere by observing the muon produced in combination with the neutrino.

between neutrinos are observed. IceCube identifies one atmospheric neutrino about every six minutes, but its main purpose is to identify astrophysical neutrinos produced by the huge astrophysical mechanisms that accelerate cosmic rays.
The main "suspects" are the most violent phenomena in the universe, like active galactic nuclei (AGN) (see fig. a., ed.), galaxies with enormous radiation power presumably fed by the black holes at their centre, and gamma ray bursts (GRBs), frightening flashes of radiation that last from under a second to several minutes, so energetic that they can reach us from the confines of the observable universe. The validity of these conjectures can be tested by observing the high-energy gamma rays emitted by these sources. But even just observing the neutrinos would demonstrate that these sources accelerate the protons and ions observed on Earth to extreme energies.
The search for cosmic messengers was crowned with success in 2012, seven years after construction started, when more than 260 international researchers involved in the IceCube experiment discovered two extraterrestrial neutrinos, which they named Ernie and Bert, from the famous television series The Muppet Show. The two neutrinos had an unusually high energy, more than one PeV. This aspect distinguished them from atmospheric neutrinos. After the detection of the lower-energy neutrinos from Supernova SN1987A in 1987, this was the second time that neutrinos coming from outside the solar system had been observed. The following year, in a fascinating race for success, a second careful analysis of data collected over two years by IceCube provided evidence of another 26 events, at slightly lower energies starting from around one TeV. A third year of data taking was added shortly afterwards, revealing a total of 37 events, including the neutrino named Big Bird after the popular American TV series which beat all previous records with its two PeV of energy!
It is not only their higher energy, but also their angular distribution that distinguishes these events from neutrinos coming from the Earth's atmosphere. The production of atmospheric neutrinos is always accompanied by muons. If these interactions with the atmosphere take place in the Southern Hemisphere, the muons can penetrate the layer of ice above the detector and emit a signal that allows them to be identified as coming from a spurious source. If they are of atmospheric origin, the events detected by IceCube should mainly come from the Northern Hemisphere, from where the muons, absorbed by the Earth, cannot reach the detector and so it is possible to "suppress" the atmospheric source. On the contrary, the IceCube events mainly cover the Southern Hemisphere. According to researchers, they unequivocally come from outside the solar system.
Investigations to study the direction of the source of the events and the time of their arrival have not yet allowed us to identify their sources: the number of detected neutrinos is still too low and it is too soon to draw conclusions. Alternative interpretations involve the new physics, invoking for example the decay or self-annihilation of dark matter (see p. 25, ed.) or an increase in the neutrino collision cross-section or the intervention of leptoquarks, presumed mediators of the interactions between quarks and neutrinos, predicted in some extensions of the standard model. These are just some examples of the interesting options, old and new, which might be able to explain these observations by IceCube.
The optical sensors continue to collect data, undisturbed beneath the geographical South Pole and researchers hope to resolve this intriguing problem in the years to come.
2013 was undoubtedly a decisive year for researchers at IceCube.

In addition to the discovery that signalled the birth of astronomy of high-energy neutrinos, which has recently been confirmed, the international team published a measurement of neutrino oscillation parameters. These characterise the transformation of the neutrinos from one type (or flavour, which may be electron, muon or tau) to another and confirm that although their mass is very small indeed, neutrinos are not massless. The oscillation parameters reported by IceCube were obtained by observing a reduction in the flux of atmospheric muon neutrinos in a particular direction and at certain energies, using the most dense part of the detector's optical sensors. This subunit, called Deep Core, is capable of recording neutrinos at lower energies, starting from a few GeV. What is relevant about this result is that it demonstrates the potential for the use of neutrino telescopes in areas of research that go well beyond astrophysics, in the race for success against competition from "targeted" experiments like Super-Kamiokande. And that they also hold some surprises. IceCube is also searching for neutrinos emerging from the annihilation of dark matter (see page 27, ed.) that has accumulated due to the gravitational pull at the centre of celestial bodies such as Earth, the Sun and our galaxy. On the other hand, lowering the energy threshold (the minimum detectable energy of a neutrino) even further to below 10 GeV, it would become possible to measure the mass hierarchy of neutrinos, meaning the order of the masses of the three neutrino flavours. With this aim, a new and bigger team of researchers are working on the PINGU project to develop a dense core with another 40 strings in IceCube. At high energies, work is being done to extend the sensitive volume of IceCube by one order of magnitude (IceCube-Gen2) to discover the source of the recently glimpsed astrophysical signal.
For neutrino telescopes this is just the beginning of an exciting new era and new revolutionary discoveries are presumably just around the corner.

c.
The IceCube laboratory at the Amundsen-Scott South Pole Station. The laboratory houses the computers that collect the data. Only events of interest are sent to the University of Wisconsin - Madison, where they are analysed by physicists working on the project.

Biography
Elisa Bernardini is professor at the University of Humboldt in Berlin and at Deutsches Elektronen-Synchrotron (DESY) in Germany. She is a member of the IceCube and MAGIC research collaborations. Before moving to Germany in 2002, she studied in Bologna and then in L'Aquila, in collaboration with the INFN's Gran Sasso National Laboratory. Between 2002 and 2005 she took part in three expeditions to the South Pole to carry out maintenance on AMANDA, the forerunner of the IceCube neutrino telescope.

Web links

https://southpoledoc.wordpress.com/tag/icecube-neutrino-observatory/

http://www.km3net.org/home.php

http://baikalweb.jinr.ru

Fundamental chords

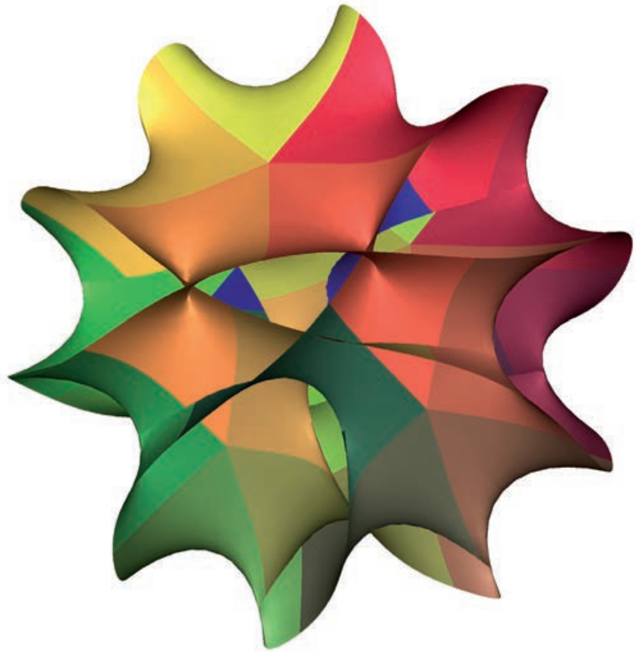
The fascinating world of strings

by Marco Serone

a.
As the chords of the violin produce different sounds according to the way in which they vibrate, similarly the different oscillations of the strings correspond to the different particles.

Right now, the string theory is the most promising theory for trying to resolve one of the biggest theoretical questions of fundamental physics: how to integrate Einstein's theory of gravity (also known as the theory of general relativity) within the framework of quantum mechanics. String theory was originally developed in 1968 for a completely different purpose (to understand strong interactions) by the Italian physicist Gabriele Veneziano. It is based on the assumption that all the elementary particles we can observe are nothing other than very small vibrating strings. Just as the strings of a violin produce different sounds depending on how they vibrate, so different oscillations of strings correspond to different particles. Strings may be closed or open and may even be tangled.
Some years after Veneziano developed his theory, it became clear that strong interactions are explained by a different theory, called quantum chromodynamics (QCD). Furthermore, at around the same time, researchers observed that the different string vibrations always included the graviton, i.e. the particle responsible for gravitational interactions. Abandoned as the theory of strong interactions, the string theory thus acquired the more ambitious status of quantum theory of gravity. Since then there have been several important theoretical developments.
String theory, whose structure is somewhat complex, seems to effectively bring together a series of ideas circulating in the field of fundamental physics to explain a number of unanswered questions, especially theoretical ones, which scientists face in the framework of the theory of general relativity and in the standard model of elementary particles. One of its main characteristics is the prediction according to which in the universe there cannot only be the three spatial dimensions that we perceive (height, width and depth), but there must be nine or ten dimensions, depending on which variant of the theory you are considering.

We cannot perceive the six or seven extra dimensions because they are wrapped around themselves on the smallest of scales (physicists use the term compactified). To render the idea, imagine a very long and rather narrow tube. If observed from a distance, the tube looks like a one-dimensional object, practically a simple line, whereas when observed from close by through a lens or with a microscope, its two-dimensional structure is visible.
Likewise, according to string theory, the extra dimensions are so subtle they cannot be observed. In order to discover the other dimensions, of which, incidentally, we do not know the exact length, we need an instrument that is much more powerful than the current LHC accelerator.
But why do we need these strings? Let me try to explain the problem more clearly.
The theory of general relativity states that space, time, energy, matter are all correlated, that is to say that spacetime, or rather its curvature, is determined by the energy and matter it contains. The spacetime curve is what we perceive as gravity. The behaviour of matter over very short distances is instead governed by quantum mechanics. Because gravity is by far the weakest fundamental force that exists in nature, we can disregard the minimum space curvature induced by the elementary particles, when studying the infinitely small. Likewise, we can forget about the quantum mechanics of elementary particles, when studying macroscopic phenomena. Thus, on one hand we have the theory of general relativity, which describes macroscopic gravitational phenomena, on the other, there is quantum mechanics, which describes the infinitely small and is the basis for all other forces of nature.
Both of these theories have been widely confirmed by experiments, each within its own regime of validity (see. p. 11, ed.), in which the others do not have a role. However, there are necessarily some energy and distance regimes in which you cannot describe a physical phenomenon using only one or the other theory. These regimes have not yet been directly explored, but at vastly smaller distances (or hugely higher energies) than those explored so far, gravity and quantum mechanics will inevitably have to be considered together. Although we do not as yet have any physical process "at hand" that requires it, from a theoretical standpoint it is absolutely essential that we understand how to combine gravity with quantum mechanics. Such a combination does not appear to be easy by any means. What makes string theory promising is the fact that, in a certain sense, it predicts the very existence of gravity, since the vibration of the string that gives rise to the graviton is always present.
On the other hand, our theory has a basic problem: at the moment, it is unclear what type of experiment could confirm or refute its validity, and this is often a cause for criticism. But the very fact that the theory comes into play in the extreme regimes of nature, which are not easily accessible, inevitably makes its experimental verification difficult. It should also be added that, regardless of the actual existence of strings, many theories have been developed within this branch of research and then migrated to the benefit of other fields of theoretical physics, so that, even only considering this aspect, the theory can already be considered extremely fruitful.



b.
Two-dimensional projection of a compact space known as Calabi-Yau. This is a very popular type of space in the string theory. As can be seen from the figure, the six extra dimensions in these types of spaces are generally rolled together in a very complicated way.

In conclusion, since many aspects of strings have yet to be clarified, it would be premature to try to establish whether the theory is just an extremely complicated (albeit very useful, at least from a theoretical perspective) mathematical invention or whether it is indeed the "theory of everything" that unifies all existing fundamental physics within a single context.
In any case, this is an ambitious concept without precedent in the history of physics and, in the absence of any equally valid alternative theories, the fascination and appeal of the string theory among theoretical physicists is entirely understandable.

Biography
Marco Serone is associate professor of Physics at the International School for Advanced Studies in Trieste (SISSA). He is mainly concerned with elementary particle physics and for several years was engaged in research in the field of the string theory.

Web links

http://www.stringwiki.org/wiki/String_theory_for_non-physicists

They are us.

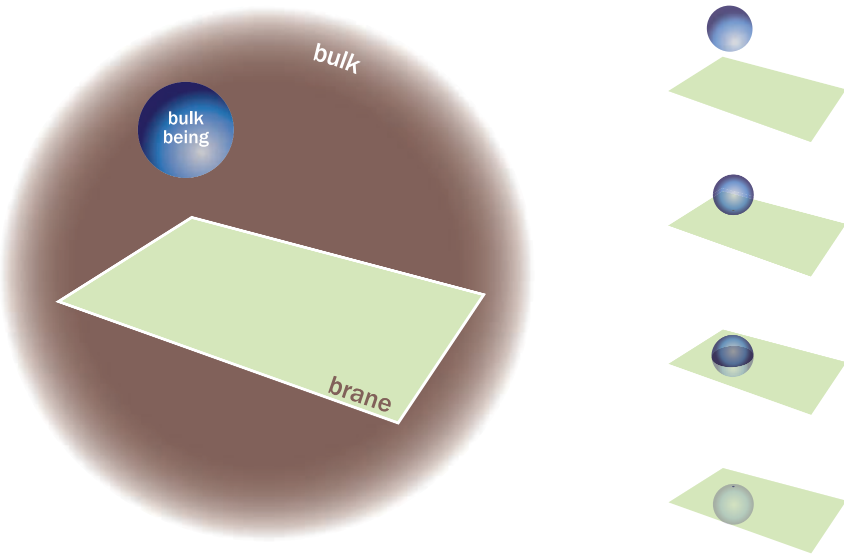
by Kip Thorne

theoretical physicist and scientific adviser for the film Interstellar

Christopher Nolan's recent film *Interstellar* is full of new physics. And that is no coincidence. Kip Thorne, a world-renowned expert in general relativity from the California Institute of Technology, agreed to act as scientific adviser for the film on condition that the scenes were consistent with present-day physical theories, or at least inspired by theoretical assumptions that are currently a research subject in physics: "educated guesses" that are not altogether unfounded (ideas that could actually become new laws of physics one day), or even outright speculations, but such that scientists of his standing could regard as plausible. Thorne himself wrote a book (*The Science of Interstellar*, published by W.W. Norton & Company) that was released with the film. An excerpt is published below.

For the film, Thorne imagines something that many physicists have actually suggested (see for example p. 42), namely that spacetime contains additional space dimensions: it is what theoretical physicists refer to as a bulk, within which there is a sub-spacetime (physicists call this a brane, from "membrane") with three space dimensions and one time dimension, corresponding to the spacetime in which we live (see left of fig. a). For *Interstellar*, Thorne imagines that there is only one extra dimension: the bulk is thus composed of five dimensions, of which four space dimensions and one time dimension. Strange beings, called "They" in the film, have managed to understand and overcome the gravitational anomalies that affect the Earth. But who are "They" and how convincing is all this? (Warning, this text contains spoilers!)

In 1844 Edwin Abbott wrote a satirical novella titled *Flatland: A Romance of Many Dimensions*. Though its satire on Victorian culture seems quaint today and its attitude toward women outrageous, the novella's venue is highly relevant to Interstellar. I recommend it to you.
It describes the adventures of a square-shaped being who lives in a two-dimensional universe called Flatland. The square visits a one-dimensional universe called Lineland, a zero-dimensional universe called Pointland, and most amazing of all to him, a three-dimensional universe called Spaceland. And, while living in Flatland, he is visited by a spherical being from Spaceland.
In my first meeting with Christopher Nolan, we were both delighted to find the other had read Abbott's novella and loved it.
In the spirit of Abbott's novella, imagine that you are a two-dimensional being, like the square, who lives in a two-dimensional universe like Flatland. Your universe could be a tabletop, or a flat sheet of paper, or a rubber membrane. In the spirit of modern physics, I refer to it as a two-dimensional (2D) brane.
Being well educated, you suppose there is a 3D bulk, in which your brane is embedded, but you're not certain.
Imagine your excitement when one day you are visited by a sphere from the 3D bulk. A "bulk being", you might call him. At first you don't realize it's a bulk being, but after much observation and thought, you see no other explanation. What you observe is this: Suddenly, with no warning and no apparent source a blue point appears in your brane. It expands to become a filled blue circle that expands to a maximum diameter, then gradually shrinks to a point and disappears completely (see right of fig. a). […]
If there are bulk beings, what are they made of? Certainly not atom-based matter like us. Atoms have three space dimensions. They can only exist in three space dimensions, not four. And this is true of subatomic particles as well. And it is true also of electric fields and magnetic fields and the forces that hold atomic nuclei together.
Some of the world's most brilliant physicists have struggled to understand how matter and fields and forces behave if our universe really is a brane in a higher dimensional bulk. Those struggles have pointed rather firmly to the conclusion that all the particles and all the forces and all the fields known to humans are confined to our brane, with one exception: gravity and the warping of spacetime associated with gravity.
There might be other kinds of matter and fields and forces that have four space dimensions and reside in the bulk. But if there are, we are ignorant of their nature. We can speculate. Physicists do speculate. But we have no observational or experimental evidence to guide our speculations. In Interstellar, on Professor Brand's blackboard, we see him speculating.
It's a reasonable, half-educated guess that, if bulk forces and fields and particles do exist, we will never be able



a.
Schematic diagram of a two-dimensional brane immersed in a three-dimensional bulk. On the right, a “bulk being” passing through the brane.

to feel them or see them. When a bulk being passes through our brane, we will not see the stuff of which the being is made. The being’s cross sections will be transparent.
On the other hand, we will feel and see the being’s gravity and it’s warping of space and time. For example, if a hyperspherical bulk being appears in my stomach and has a strong enough gravitational pull, my stomach may begin to cramp as my muscles tighten, trying to resist getting sucked to the center of the being’s spherical cross section. […]
All the characters in Interstellar are convinced that bulk beings exist, though they use that name only rarely. Usually, the characters call the bulk beings “They”. A reverential They. Early in the movie, Amelia Brand says to Cooper, “And whoever They are, They appear to be looking out for us. That wormhole lets us travel to other stars. It came along right as we needed it”.
One of Christopher Nolan’s clever and intriguing ideas is to imagine that They are actually our descendants: humans who, in the far future, evolve to acquire an additional space dimension and live in the bulk. Late in the movie, Cooper says to TARS, “Don’t you get it yet, TARS? They aren’t beings. They’re us, trying to help, just like I tried to help Murph”. TARS responds, “People didn't build this tesseract” (in which Cooper is riding). “Not yet”, Cooper says, “but one day. Not you and me but people, people who’ve evolved beyond the four dimensions we know”.
Cooper, Brand, and the crew of the Endurance never actually feel or see our bulk descendants’ gravity or their space warps and whirls.
That, if it ever occurs, is left for a sequel to Interstellar. But older Cooper himself, riding through the bulk in the closing tesseract, reaches out to the Endurance’s crew and his younger self, reaches out through the bulk, reaches out gravitationally. Brand feels and sees his presence, and thinks he is They.

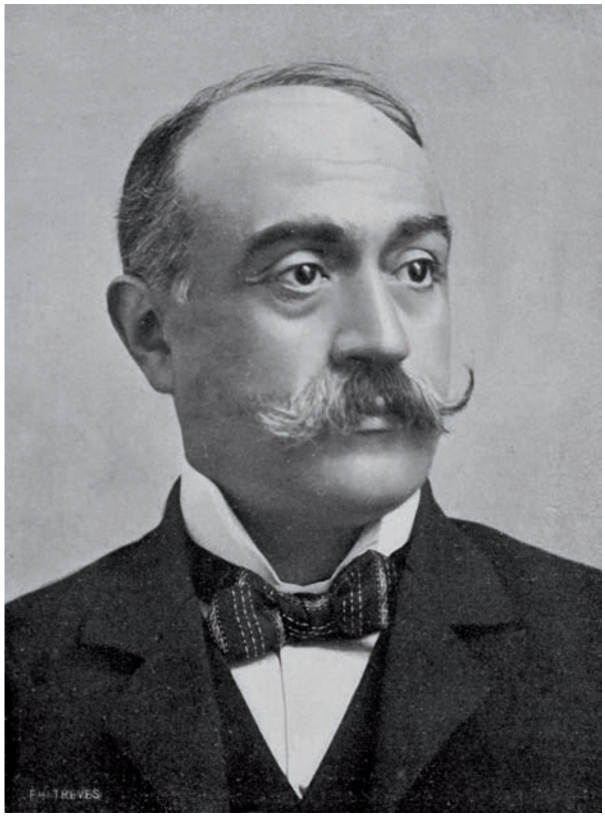
b.
From left to right, David Gyasi (who interprets the astronaut Romilly), Kip Thorne, Anne Hathaway (Amelia Brand in the film), Jessica Chastain (Murphy Cooper), Michael Caine (professor Brand) and Stephen Hawking (friend of Kip Thorne, who’s life recently has been showed in the film *The Theory of Everything*) during the preview of *Interstellar* in London.

[as] roots

The new, a hundred years ago.

by Giuseppe Giuliani

physics historian

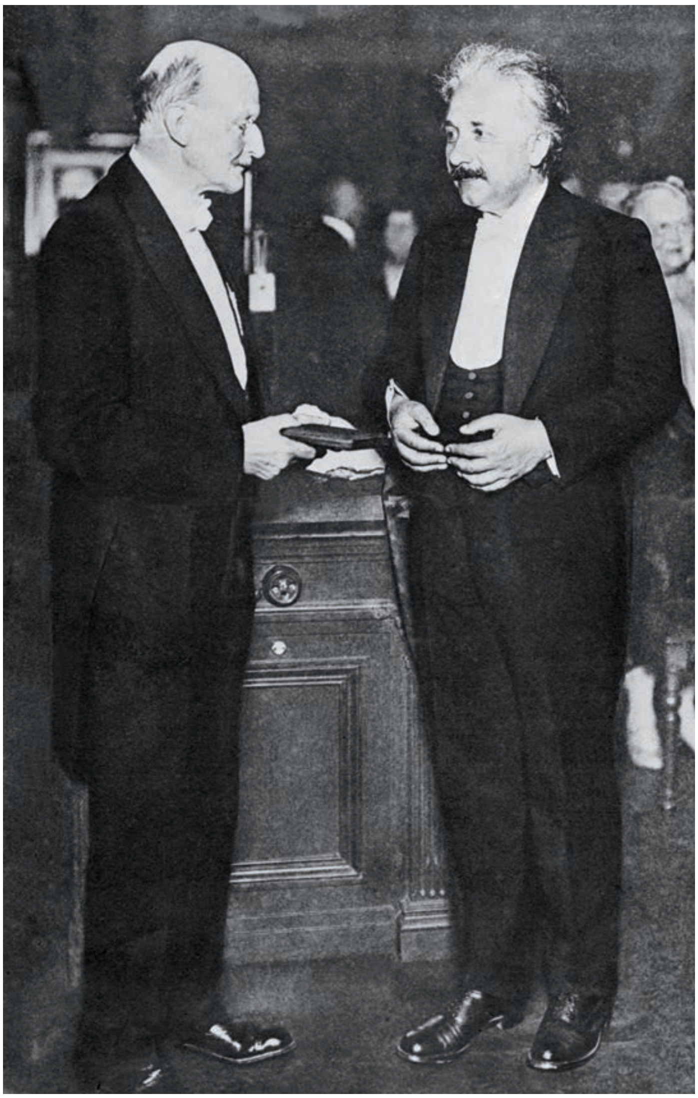


a.
Augusto Righi coined the term "new physics" in 1912, referring to the discoveries of the late nineteenth and early twentieth centuries.

The expression "new physics", which is the name given today to the set of theories and phenomena that go beyond the standard model of fundamental interactions, was first used about a century ago.
In the late nineteenth century, mechanics, thermodynamics and electromagnetism constituted the theoretical foundations of physics. Within just a few years, the study of electrical conduction in rarefied gases, which began in the mid-nineteenth century, gave rise, directly or indirectly, to a number of important discoveries: X-rays (1895), natural radioactivity (1896), the electron (1897). It was with reference to these phenomena that Augusto Righi, the most famous Italian experimental physicist of the time, coined the term "The New Physics" for the title of a conference held in 1912 at the Italian Society for the Advancement of Science (Società Italiana per il Progresso delle Scienze - SIPS). These annual meetings were an important opportunity for interdisciplinary discussion and dissemination of the results of scientific research.

Starting from the early 1900s there were a host of new discoveries in physics. In 1900, Max Planck introduced the "constant of nature" h (later designated with his name) in a successful – though not altogether precise (as Einstein argued in 1906) – attempt to explain the radiation in a hollow body when thermal equilibrium is attained ("black body" radiation), later (1905-1907) interpreted by Einstein as the source of discontinuity in the distribution of energy in different physical systems: beams of light and atoms that oscillate in crystals around their equilibrium positions. According to Einstein, light, under certain conditions, could be described as consisting of "light quanta" (later called photons), whose energy was linked, through Planck's constant (h), to the frequency of light described as an electromagnetic wave.
In 1911, Ernest Rutherford showed that atoms, in addition to electrons, contain a positively charged nucleus. In 1913, Niels Bohr, on the basis of the atomic model of Rutherford and assuming (with the use of the constant h) that the energy of

the electron of the hydrogen atom could only assume discrete values, found an explanation for the electromagnetic radiation emitted or absorbed by the atom, surprisingly in agreement with the experimental data obtained some time earlier. In the meantime (1912), Max von Laue demonstrated that crystalline solids act as diffraction gratings for X-rays, thus opening the way for experiments to study crystalline structures. Incidentally, this technique eventually led to the discovery of the DNA structure (1953).
In parallel, Einstein worked on Newtonian dynamics and gravity to develop, respectively, the special theory of relativity (1905) and general relativity (1916).
This led to a thorough review of the concept of matter: atoms, regarded as a heuristic hypothesis in the nineteenth century, became the subject of direct experimental and theoretical study. In the following decades, quantum mechanics, quantum electrodynamics and quantum chromodynamics emerged as powerful tools in theoretical investigations of atomic and subatomic phenomena. Knowledge about the microscopic world also opened new avenues for understanding cosmic phenomena and drafting a model to explain the origin of the universe.
Since the end of World War II, experimental research has increasingly gone hand in hand with technology to the point that we can now speak of “techno-science”: scientific investigation relies on the products of technology, which are, in turn, fuelled by new knowledge. Alongside problems associated with the need for social control over technology are those due to the persistence of irrational beliefs, the legacy of past centuries, that constantly re-ignite antiscientific attitudes.
Scientists too must take part in this cultural battle by disseminating their knowledge and promoting what, a century ago, when “new physics” was born, Vito Volterra, founder of the SIPS and some of the most important scientific institutions in Italy, called “scientific sentiment”.



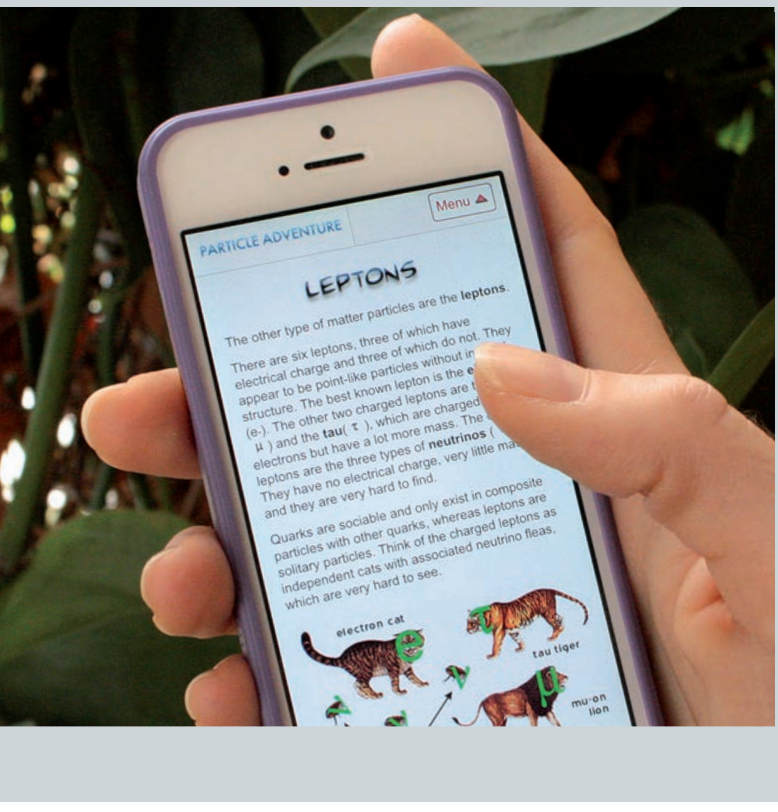
b.
Max Planck (left) awards the “Max Planck medal” of the German Society of Physics to Albert Einstein in Berlin on June 28, 1929.

[as] illuminations

Just a click away.

Browsing information about the Higgs boson or the search for new physics instead of the latest photos of friends' holidays? Nothing could be simpler, if you have downloaded the new *The Particle Adventure* app available free since last November for iOS and Android.
The history of *The Particle Adventure* goes back a long way. It was in 1989 when the first version was written using HyperCard, a program for writing hyper texts before the advent of the World Wide Web. In an era when the word "neutrino" was almost only heard among specialists and the Higgs boson had not yet filled the front pages of newspapers around the world, *The Particle Adventure* was the first attempt to make the standard model of particles and the knowledge that had led to its formulation accessible to a wide audience. In 1995 the program was converted into a website, http: //www.particleadventure.org/, which received nearly five million visits in the first year and has continued to be among the sites most frequently visited by students and onlookers from all over the world. The website is available in various languages.

The creation of the app (funded by the US Energy Department and for now only available in English) is another step in spreading the fundamental ideas of physics and will also be very useful for students studying modern physics in the last year of high school.
The most important discoveries and ideas of recent decades, from quarks to the Higgs boson, from neutrinos to the unification of fundamental forces, are organised in five main courses: "The Standard Model", "Accelerators and particle detectors", "Higgs boson discovered", "Exploring unsolved Mysteries" and "Particle decays and annihilations". The contents of the app were developed by physicists with expertise in various sectors, while the design, graphics and especially the humorous parts were developed by physics students. And they appear to have done an excellent job, if you think that one teacher, who was very sceptical at first about teaching modern physics at high-school, said that *The Particle Adventure* made him change his mind, because the careful blend of humour, graphics and science caught the students' attention and kept them happily clicking on their smartphones. [Barbara Sciascia]



To download The Particle Adventure app:
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https://itunes.apple.com/us/app/the-particle-adventure/id924683946?ls=1&mt=8 (iOS)

Istituto Nazionale
di Fisica Nucleare

The laboratories of the Italian National Institute for Nuclear Physics are open to visitors.

The laboratories organize free tours for schools and the general public on request and by appointment.
Visits last about three hours and include an introductory seminar on the activities of the INFN and the laboratory and a tour of the experiments.

See also the website
www.asimmetrie.it
(only in Italian).

Asimmetrie is also an app,
with lots of additional multimedia content
(only in Italian).

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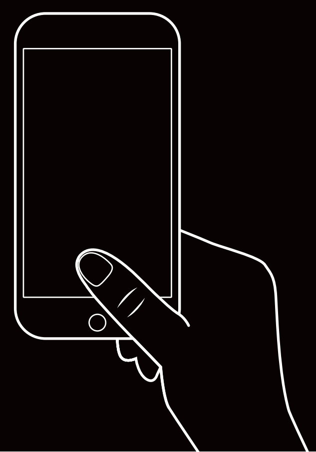

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