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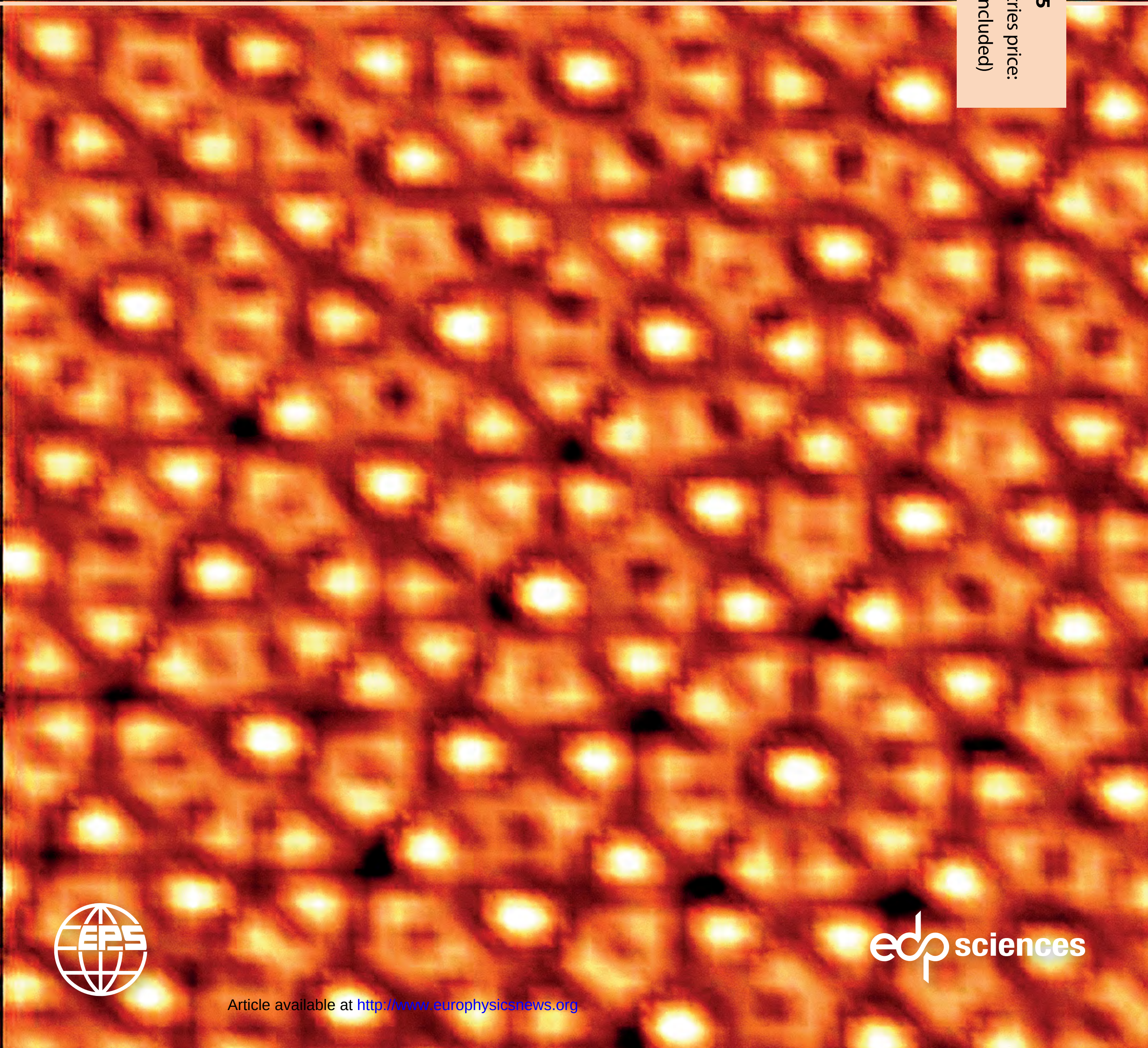

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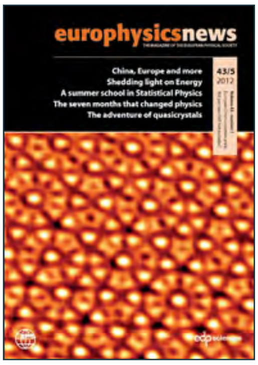
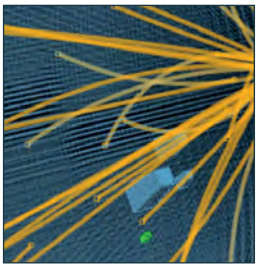


Cover picture: Scanning Tunnelling Microscope image of an order 5 surface in a quasicrystalline AlPdMn phase (73x73 nm^2).
This a multiscale metallurgy image made in Nancy, France.

▲ PAGE 10

50 years of a school in Statistical Physics



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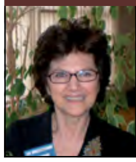


China, Europe **and more**

A delegation of the European Physical Society (EPS) was invited to participate in the celebration of the 80th anniversary of the Chinese Physical Society (CPS), on August 25, 2012, at the Tsinghua University, Beijing. The official ceremony took place in the morning, in the huge University auditorium.

A formal greetings address was delivered by former EPS president Maciej Kolwas, along with other addresses by distinguished representatives of the major physical societies in the world (fig. 1). The growing role of the CPS in developing cooperation with insitutions from other countries and regions, including the EPS, was acknowledged. The first formal exchanges CPS-EPS began in 1995, at the 2nd World Congress of Physical Societies, which was organised in Japan by the Physical Society of Japan (PSJ), the Japan Society of Applied Physics (JSAP) and the Association of Asia Pacific Physical Societies (AAPPS). The American Physical Society (APS) had organised the 1st World Congress of Physical Societies in 1986 in the US.

The EPS organised the 3rd World Congress of Physical Societies in Berlin, in 2000. In addition to resolutions regarding physics education, physics communication, and the role of physical societies, more than 45 countries endorsed a resolution calling for a World Year of Physics. The CPS was active in this world wide outreach activity demonstrating the contributions of physics to cultural, economic and societal development.

More recently, the CPS has made important contributions through the AAPPS to the co-organisation with the EPS of the Asia Europe Physics Summit (ASEPS). The ASEPS meetings address issues relating to the enhancement of cooperation and collaboration in physics research, education and outreach. Following the success of the first two ASEPS meetings, ASEPS3 will be organised in Chiba, Japan in July 2013.

▲ **FIG.1:** Former EPS President Maciej Kolwas during the ceremony

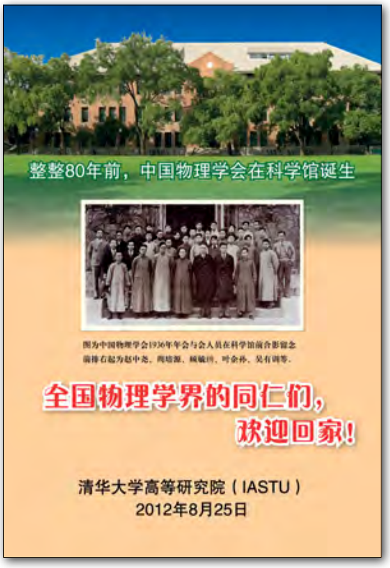
▼ **FIG.3:** The Joint Meeting of the International Physical Societies representatives (see text)

In the afternoon a restricted **Joint Meeting of International Physical Societies** was held in the historical Science Building of Tsinghua, where CPS foundation actually occurred in 1932 (fig. 2). During the meeting, a very friendly and informal presentation of the various societies and a round table discussion took place. The participants, warmly welcomed by CPS president Zhan Wen-Long, included, in addition to Maciej Kolwas and myself for the EPS, presidents and representatives from the American Physical Society (APS), the Institute of Physics (IOP), the German Physical Society (DPG), the Physical Society of Hong Kong (PSHK), the Japan Society of Applied Physics (JSAP), the Physical Society of Japan (PSJ), the Association of Asia Pacific Physical Societies (AAPPS), and a number of CPS delegates. (fig. 3)

Various matters were discussed, ranging from education, membership and recruitment, equal opportunities, international cooperation, editorial policy and open access, joint initiatives, *etc.* Similarities and diversities were duly pointed out, and such a wide-range comparison among societies around the world was in my view extremely useful, interesting and enriching. ASEPS and encompassing initiatives like the International Year of Light were of course vigorously encouraged.

We all agreed that research, particularly in physics, is a global undertaking. Physicists know this, through their research, publications and career development. Physical societies, through occasions such as these, share information, and best practice, and work in a very real and personal capacity to improve international communications and cooperation.

▼ **FIG.2:** The poster of the 80th anniversary of the Chinese Physical Society celebration



So thanks to the CPS for the pleasure of having been with them in Beijing, and our best wishes for continued success, strength and vitality. ■

■ **Luisa Cifarelli**
President of the EPS

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EPS Plasma Physics Division reports

Outstanding scientists were honoured for their remarkable scientific or technological results at the EPS / ICPP Conference 2012 (Stockholm, July 2-6, http://epsicpp2012.spp.ee.kth.se/) at which the new EPS Plasma Physics Division Board was elected.

The EPS-PPD Hannes Alfvén Prize 2012

It is awarded to **Eugene N. Parker** (University of Chicago, United States of America)

"for his theoretical discovery of the transonically expanding atmosphere in cool stars as a basic phenomenon in the magnetic astrophysical cosmos".

Professor Eugene N. Parker reported his theoretical discovery of the transonic expansion as the natural state of a magneto-hydrodynamic atmosphere in two fundamental papers on the '*Dynamics of Interplanetary Gas and Magnetic Fields*' and '*The Hydrodynamic Theory of Solar Corpuscular Radiation and Stellar Winds*' published in 1958 and 1960. This theory led him to predict the existence of the solar and stellar winds.

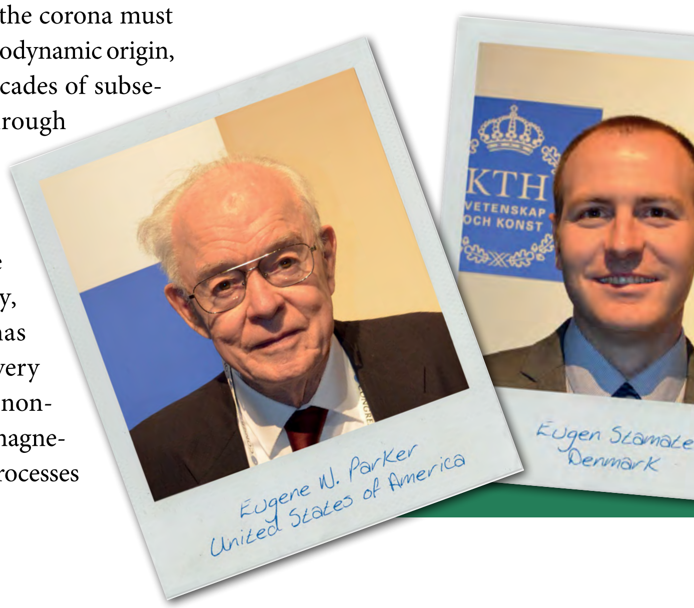
A hydrodynamic model is used in these papers to establish the inevitability of the transonic expansion when a corona is maintained at a million-degree temperature. Remarkably ahead of its time, Parker's 1960 paper shows that the heating of the corona must have a magnetohydrodynamic origin, as confirmed by decades of subsequent research. Through his prolific seminal publications and four well-read monographs in the past half-century, Professor Parker has led us in the discovery and exploration of non-linear plasma and magneto-hydrodynamic processes of astrophysics.

The EPS-PPD Plasma Physics Innovation Prize 2012

It is awarded to **Eugen Stamate** (Technical University of Denmark; Denmark)

"for the discovery of the modal and discrete focusing effects associated with three-dimensional plasma-sheath-lenses that contributed to ion beam extraction, mass spectrometry, control of the ion flux on substrates and the development of new sensors for plasma and sheath parameters".

The plasma sheath, concept first introduced by Langmuir in the 1920´s, is generated by the interaction of the plasma with the boundary material. The research work led by E. Stamate has revealed discrete and modal focussing effects in a three-dimensional plasma sheath lens with applications to sheath diagnostics, negative and positive ion extraction, mass spectroscopy and control of ion dose in plasma ion implantation.



The EPS-PPD Landau-Spitzer Prize 2012

This new award is jointly sponsored by the American Physical Society (APS) and the EPS for outstanding contributions to plasma physics. The joint APS-EPS selection committee was comprised of six members chaired by Richard Dendy. It is awarded to **Sergey I. Anisimov** of the Landau Institute for Theoretical Physics (Russian Academy of Sciences) *"for outstanding contributions to plasma physics ranging from fundamental plasma theory to laboratory plasmas, controlled inertial fusion and astrophysical phenomena, particularly in the areas of laser interaction with plasma, plasma dynamics and stability, compressed matter and turbulence".*

The EPS-PPD PhD Research Award 2012

It has been recently judged by a committee comprising Manfred Thumm and John Allen who examined all the candidatures in a process managed by Dimitri Batani (EPS-PPD). This prize is a key element of the Division activities to recognise exceptional quality in work carried out by young scientists. The awardees are in alphabetic order:

Bart Hennen (FOM Institute / Eindhoven University of Technology, The Netherlands) for a thesis on *"Feedback control for magnetic island suppression in tokamaks"*.

Frédéric Pérez (Laboratoire pour l'Utilisation des Lasers Intenses, Palaiseau, France) for a thesis on *"Study of supra thermal electron transport in solid or compressed matter for the fast-ignitor scheme"*.

▲ IUPAP 2012 Young Scientist Prize in Plasma Physics. Left to right: B. Hennen, F. Pérez, J. Waskoenig and C. Hidalgo (chair)

Jochen Waskoenig (Queen's University Belfast, UK) for a thesis on *"Numerical simulations of the electron dynamics in single and dual radio-frequency driven atmospheric pressure plasmas and associated plasma chemistry in electro-negative He-O_2 mixtures"*.

IUPAP 2012 Young Scientist Prize in Plasma Physics

The IUPAP Commission 16 Young Scientist Prize recognizes exceptional achievement in the study of plasma physics by scientists at a relatively junior stage of their career. It is awarded to: **Ian Chapman** (Culham Centre for Fusion Science, UK) *"for his outstanding experimental work with deep understanding of theory and simulations of plasma instabilities in magnetically confined fusion plasmas"*.

The EPS Plasma Physics Division Board / Elections 2012

In accordance with the statutes of the Plasma Physics Division of the EPS, **Carlos Hidalgo** will be succeeded by **Sylvie Jacquemot**, who was elected by the EPS PPD Board at its meeting held in Madrid on December 13th 2011. Six members of the present Divisional Board are retiring from it: Dimitri Batani, Pascale Monier-Garbet, Elisabeth Rachlew, Boris Sharkov, Wolfgang Suttrop and Jörg Winter. The Division is grateful for their many contributions. Their replacements have been selected by a process of direct election by the full members of the European Physical Society. The election process for the Board of the EPS Plasma Physics Division was completed by May 18th in a process efficiently managed by Boudewijn van Milligen. Thus, Daniela Farina, Holger Kersten, John Kirk, Piero Martin, Emilia R. Solano and Elisabeth Wolfrum were elected.

The new EPS Plasma Physics Board has the following composition:
Sylvie Jacquemot (chair), Richard Dendy (vice-chair), Dirk Van Eester, Daniela Farina, Leo A. Gizzi, Javier Honrubia, Holger Kersten, John Kirk, Thomas Klinger, Bertrand Lembege, Piero Martin, Emilia R. Solano and Elisabeth Wolfrum. ■

■ **EPS Plasma Physics Division**
(Stockholm, July 2012)

Shedding light on Energy

by Enzo De Sanctis

The first Course of the Joint EPS-SIF International School on Energy, devoted to all physics fields with relevance for the technologies of energy production, conversion, transmission and saving, came to a close on August 4th, leaving students and participants very satisfied by the lectures given at the beautiful location of Villa Monastero at Varenna on Lake Como.

Like food, air, and water, energy is essential to human existence. The hopes of billions of people for a better life depend on plentiful and accessible sources of energy. Recent events such as the conflicts within several North African and Middle East oil- and gas-exporting countries, and the nuclear disaster following the dramatic tsunami in Japan have added elements of uncertainty in the already complex evolution of the energy situation in the world and in Europe in particular. Security of supply, geopolitical aspects and environmental problems are once more at the forefront. Consequently, one of the central challenges of the 21st century is to ensure a sustainable energy supply for the world's people and its economy. In a world characterized by strikingly unequal rates of energy consumption it will be difficult to collectively develop rational responses to global climate threats. Furthermore, energy inequalities increase the potential for resource-based geopolitical conflicts, and foster unhealthy consumption habits throughout the developed world, while preventing entire generations of people in the developing world from fully realizing their potential as citizens of the modern world.

To evidence the dramatic diversity in the world energy consumption, it is instructive to observe in Fig. 1 how many people in the world do not have access to electricity.

Moreover, among the people the awareness of various aspects of energy use and production remains low and the interest for science discoveries cohabits with a widespread lack of a "critical knowledge". This often produces fear, mistrust, and also opposition towards many advanced technologies and innovations. Understanding the nature of risks and uncertainty is needed for many public policy issues and for everyday decisions in our personal lives. Clearly, an uninformed public is very vulnerable to misleading ideas. Awareness and understanding of scientific ideas and issues by the public at any level is necessary to produce an enhanced ability to sift the plausible from implausible and to make the right decision, if the world is to regulate carbon emission, control overpopulation or make the best use of advanced technologies.

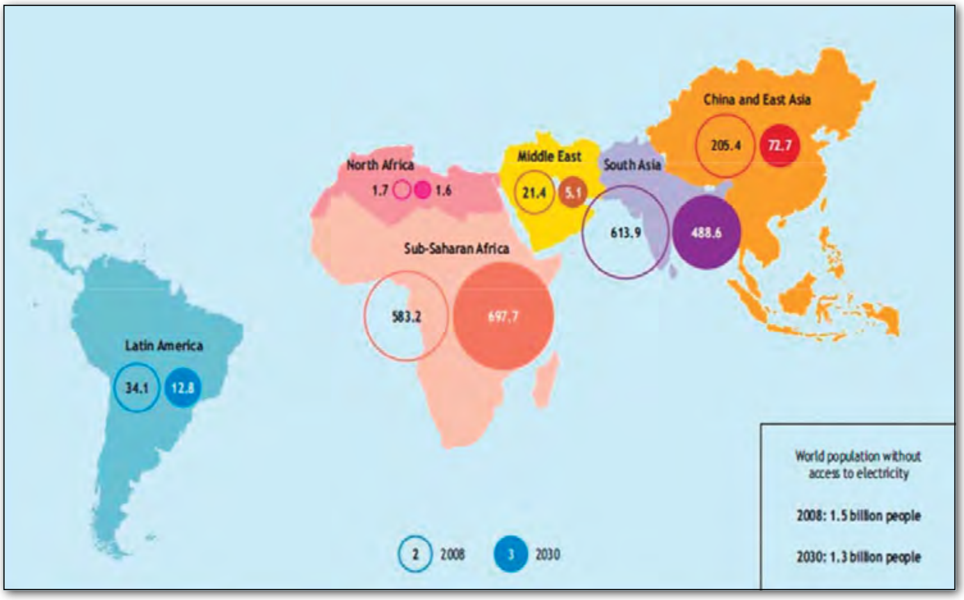
In this scenario, very timely the European and Italian Physical Societies (EPS and SIF) have jointly taken the suitable initiative of establishing an International School on Energy to support education and training on energy issues at post-doctoral level. The school also aims at providing a regular forum of discussions for an analysis of the new developments and a new vision of the future for scientists interested in any aspect of physics research and development related to the science of energy and technologies for the supply, distribution, transformation and use of energy in society.

The School will hold its courses every other year in the Villa Monastero in Varenna on Lake Como, Italy. The location is splendid: Varenna is undoubtedly one of the most beautiful and characteristic villages on the eastern bank of Lake Como, and Villa Monastero is one of the most ancient and famous villas of the region. The mild climate and the picturesque surroundings guarantee a relaxing and peaceful stay.

The first Course of the School, entitled "New strategies for energy generation, conversion and storage", was held this year from July 29th to August 4th. It was devoted to all physics fields with relevance for the technologies of energy production, conversion, transmission and savings.

Luisa Cifarelli, of Bologna University, Friedrich Wagner, of Max-Planck IPP, Greifswald, and Diederik Wiersma, of

▾ Fig. 1: People in the world without electricity in 2008 and in 2030 (figures in the open and full circles, respectively) [Source: OECD/IEA 2009]



LENS and CNR-INO, Florence, chaired the School, which has attracted 67 participants from 18 countries (see Fig. 2). Twenty-five lectures, followed by animated discussions also during breaks and dinners, focused on the most recent findings, ideas and suggestions for future developments in solar photovoltaic and photo-thermal sources, hydro, wind, biomass, fossils, fission, fusion, energy saving technology, climate issues, along with other topics where physics plays a role.

The school started with a lecture by Enzo De Sanctis (INFN-Frascati) on the importance of energy communication today, when the world is confronted with a number of immediate, urgent problems. He also stressed the need of communicating with society to create a climate of reciprocal knowledge and trust between science and society, establishing an authentic dialogue with the public. A better understanding of science, its aims, thinking process and method can produce better support and understanding from the public, as well as a new level of interest and enthusiasm for research.

Marco Ricotti (Politecnico di Milano) overviewed, in three lectures, the present and future situation of nuclear fission. Modern power stations using fission are considerably safer than older ones such as those at Fukushima. This is because of stronger containment structures, more secure storage of spent fuel rods and emergency systems to prevent overheating. Future developments will greatly reduce the volumes of radioactive waste produced.

Sheshti Johansson (Uppsala University) presented, in two lectures, reference figures on global food production and biofuel potential, and discussed different biofuel technologies and energy accounting methods that can make figures on energy return of biofuel production rather confusing.

In his two lectures, Friedrich Wagner (Max-Planck-Institute for Plasma Physics, Greifswald) introduced students into the role of fusion as a basic mechanism to fuel the universe with elements and energy, discussing the processes for technical fusion and the fusion conditions. Then he dealt with the confinement of the fusion plasmas by strong magnets in toroidal geometry. The alternative physics characteristics of the major toroidal confinement systems, their advantages and disadvantages and their complementarities were presented. Finally, he reported on the present status of fusion research, the accomplishments in the past, the design of the fusion reactor ITER, which will be the first fusion device to produce energy in a larger scale, and a short introduction to the first fusion power plants.

F. Wagner gave also a seminar in which he discussed characteristic trends and the mostly system-oriented consequences of large-scale wind and photovoltaic use for electricity production. Specifically, he analysed some features of electricity production based predominantly on wind onshore and offshore, and on photovoltaic generation. Actual data were taken from the German situation in 2010, and the generation capacities were scaled to higher installed powers.

Diederik Wiersma (LENS and CNR-INO, Florence) discussed the possibilities offered by disorder in photonics to create extremely efficient, and simple-to-realize traps for light waves for solar energy applications and innovative lighting.

Jo Hermans (Leiden University) analysed the efficiency of various transport systems, using elementary physics principles. In his lecture, he looked at cars, buses, trains and TGVs, ships, aircrafts and zeppelins. He also considered the efficiency of human powered vehicles, arriving at the surprising conclusion that cycling beats every mode of transport, if one measures the amount of energy per kilogram of displaced mass per unit distance, as shown in the figure 3.

▲ **Fig. 2: Picture of the participants at the first Course of the Joint EPS-SIF International School on Energy at Varenna, Lake Como**

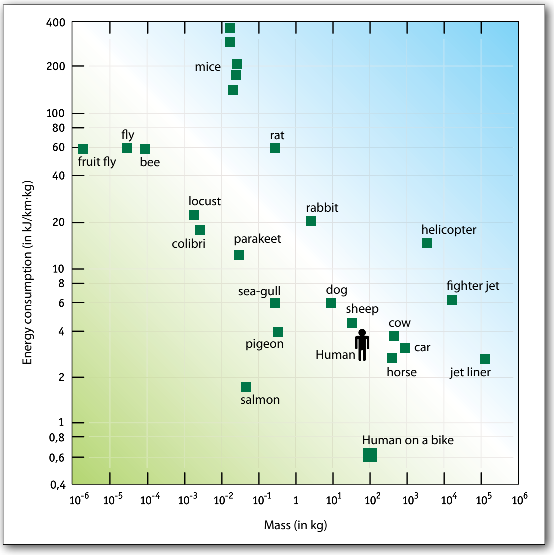
Hartwig Freiesleben (Dresden University) presented the origin and properties of radioactive waste as well as its classification scheme (low level waste - LLW, intermediate level waste - ILW, high level waste - HLW). He reviewed the various options for conditioning, storage and final disposal of waste of different levels of radioactivity and discussed the current situation of final waste disposal in a selected number of countries, also detailing the role of the International Atomic Energy Agency with regard to the development and monitoring of international safety standards for spent nuclear fuel management as well as radioactive waste management.

In his first lecture, Hermann-Josef Wagner (Bochum University) explained the basics of physics and technology of the wind use, presenting the status for electricity production and discussing the technical elements of an onshore and offshore windmill. In the second lecture, he provided students with the information to understand how wind-energy converters work and what the present status of market introduction is. He also explained how eco-balances are working and gave the results of the eco-balance of the offshore wind park alpha ventus constructed on the high seas in Germany.

In his two lectures, Christian Ohler (ABB Group, Switzerland) provided an introduction into electric power transmission and distribution grids from a physicist's point of view explaining the design, material selection and geometrical shape of the main power system components – overhead transmission lines, transformers, synchronous generators, and circuit breakers. He also illustrated concepts that deal with the trade-off between efficiency and cost, and discussed real-world examples, such as the heating of buildings, power electronic motor drives, direct current transmission of electric power, and electrothermal energy storage.

In his first lecture, Matthias Gaderer (Technische Universität Munich) illustrated the basics of the thermodynamics of thermal power plants and discussed steam power plants, gas turbine cycles and combined cycles. In his second lecture, he discussed advanced power plants and future requirements due to the strongly increasing renewable power production. Topics like the 700 °C power stations, coal gasification, CO_2 separation, CO_2 storage and methanation of CO_2 were also discussed.

Pavlos Lagoudakis (Southampton University) presented recent advances in the new field of hybrid optoelectronics in architectures where non-radiative energy transfer is used to combine the high carrier mobility of single crystal inorganic semiconductor heterostructures, and the versatility offered by colloidal nanocrystal quantum-dots and organic semiconductors, both in light and light emitting applications.



▲ Fig. 3: Comparison of the energy used per kilometer and per kilogram transported mass, arranged from light (left) to heavy (right). Walking is already fairly efficient compared to flying and other modes of transport, including those in the animal world. But cycling beats them all.

In his two lectures, Hermann Held (Hamburg University) recalled the environmental target adopted under the UNFCCC[1] framework in 2010 to limit what is generally assumed as the anthropogenically driven increase of global mean temperature to 2 °C compared to preindustrial values. He argued that, while setting environmental targets is at odds with some key principles of economics, it helps nevertheless to stimulate welfare-improving societal action. He then highlighted why target approaches often require a somewhat different implementation when dealing with uncertainty, and anticipated future learning. He finally outlined latest developments within the climate-energy-economic context.

Harald Johansen (Institute for Energy Technology, Kjeller) gave an overview of the available technologies of Carbon Capture Sequestration, presenting strong and weak points, and discussing the main features involved and breakthroughs required in the implementation of CO_2 capture technologies.

Augustin McEvoy (Ecole Polytechnique Fédérale de Lausanne) first recalled the history of electrochemistry stating it is the source of all our electrical engineering and technology. Then he presented the electrochemical series, and the concept of redox-reactions. Treatment of over potentials and electro catalysis led to a consideration of electrochemical applications in metallurgy, then in relation to energy technology, batteries, fuel cells and electrochemical photovoltaics.

Piergiorgio Antonini (Centro Fermi, Roma) showed that the concentrated photovoltaic technology is a mature technology. He also illustrated that, despite the very simple principle, it implies the mastering of very different technological fields: optics, thermal management, fine mechanics, simulation tools, experimental skills, production techniques, science of materials, meteorological science, and many others.

Mario Milanese (Politecnico and Kitenergy S.r.l., Torino) overviewed the basic concepts of airborne wind energy and the results that have been up to date accomplished, with a focus on a particular class of airborne wind

[1] The United Nations Framework Convention on Climate Change (UNFCCC or FCCC) is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro from June 3 to 14, 1992. The objective of the treaty is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

▼ Table 1: Questions asked to the four working groups formed by students

Name of Students' Group	More/less	What is?
µ Joule	Energy of burning a match versus lifting 10 kg by 1m.	PV surface equivalent to have power of large nuclear power plant
Nanohybrid	Mass of the atmosphere versus mass of the Alps.	Energy stored by 1 km² of rain forest in 100 years.
CO_2	Kinetic energy of cyclist versus drifting continent.	Δh of Lake Como to buffer 24 hrs energy need of Milan.
Wingkite	Power consumed by all mosquitos on earth compared to trains worldwide	By how much would the orbit of Earth need to be changed to offset a 5°C temp change?

energy generators, namely with flexible wings and ground level generators, and emphasis on optimization and control aspects. He also delineated what challenges are still to be faced, in order to fully demonstrate the viability of airborne wind energy.
Three special sessions were devoted to short talks by students on their specific researches. The best two presentations, by Fabrizio Armani (Milano University) on "Perspectives of off-shore geothermal energy in Italy" and Michal Ptáček (Brno University of Technology) on "Dynamic Model of Network – the Cooperation of renewable power sources with fuel cells", were awarded a prize of 350,00 € and 250,00 €, respectively. Two more presentations, by Gonzalo Rios Cruellas (University of Twente, Enschede) on "Benchmarking Cooling Technologies" and Giulia Sonetti (Fusion, Sevilla) on "Energy and Architecture: an overview, a case study and some suggestions", were prized with special mentions. All four talks will be published as an appendix in the School Lecture Notes.
Moreover, in a group work discussion session, led by D. Wiersma, students were divided into four groups, named μJoule, Nanohybrid, CO_2, and Wingkite (see Table 1). To each of them were assigned two ill-defined problems with the request of better defining them and of proposing reasonable solutions. Students took the task very seriously and with enthusiasm, finding interesting solutions that were deeply and lively discussed.
Finally, L. Cifarelli organized, together with Gianluca Alimonti (INFN Milano), enrolled as "observer" in the School, a "summary and highlights" presentation. The most striking and salient points of each lecture were recalled, underlying the need – as stressed in all of them – for an intense R&D activity in all fields. Everyone agreed that no single energy carrier or technology will suffice to safeguard our future energy supply. Researchers must examine a broad range of options and develop many different kinds of technologies. Only new investments on R&D can allow meeting the growing demand for energy in a responsible, equitable, and sustainable way.
For all of the talks, see the SIF website www.sif.it/attivita/scuola_energia/2012. All lectures and seminars will be soon published by SIF in a new volume series, entitled "Lecture Notes of the Joint EPS-SIF International School on Energy", and made available online and open-access. ■

Everyone agreed that no single energy carrier or technology will suffice to safeguard our future energy supply.

About the author
Enzo De Sanctis is Senior Associate (former Research Director) at INFN-Frascati, Councilor of the Italian Physical Society (SIF), Member of the EPS Energy Group, and Editor in Chief of The European Physical Journal A: Hadrons and Nuclei.

EPS PRIZE FOR RESEARCH IN LASER SCIENCE AND APPLICATIONS

Charter
The European Physical Society (EPS) Prize for Research in Laser Science and Applications is a major prize awarded on behalf of the European Physical Society through its Quantum Electronics & Optics Division (QEOD). The prize is awarded every 2 years in recognition of recent work by one or more individuals (no more than three) for scientific excellence in the area of laser science and applications in its broadest sense. Relevant topics include laser source development, power-scaling concepts, pump source development, nonlinear optics, ultrafast sources, material science, spectroscopic and characterisation techniques, and applications both in optics and photonics as well as in other fields.
The work for which the individual(s) is/are nominated must be such that a significant component of it was performed during the period 5 years prior to the award. In addition, the award will recognise research for which a significant portion of the work was carried out in Europe or in cooperation with European researchers, and may be given for either pure or applied research.
Nomination packets will consist of a CV and publication list of the nominee(s), a 2 page summary of the significance of the work which is the subject of the nomination, a suggested citation, and up to 4 letters of support.
The Prize Ceremony and Lecture will be highlights of the EPS Europhoton Conference on "Solid-State, Fibre and Waveguide Coherent Light Sources" organised every 2 years.

Additional Information and Rules
The award will be accompanied by an engraved glass medal, certificate, and a monetary sum whose value shall be determined by the QEOD board in the year preceding the award, and which will be set at 2000 euros for 2013-2014.
The monetary prize value shall always be less than the most senior Quantum Electronics (Pure and Applied) prizes of the Division which are awarded in conjunction with CLEO Europe-EQEC during the same two year period.
The prize is funded in the first instance from any financial surplus from the Europhoton Conference. In the event of no such surplus, the prize money will be awarded from the reserve of the QEOD.
The prize jury shall consist of eight eminent researchers selected from amongst the QEOD board and current or past members of the Programme Committee of the Europhoton Conference. The President of the EPS will also serve on the prize jury. Final confirmation of the prize award will be made by the EPS Executive Committee and no communication of the award to nominees will be made before the Executive Committee approval.

These conditions can be modified by the European Physical Society QEOD Board and/or the European Physical Society Executive Committee. ■

The 50 years of a summer school in Statistical Physics

In June 2013 the 13th edition of the Summer School on *Fundamental Problems in Statistical Physics (FPSP)* will be organized in Leuven, Belgium. The school not only deals with modern trends in statistical physics, but also treats fundamental problems in the field. In this article, the founding father of the school, Eddie Cohen, explains how this 50 years old event started and survived.

Introduction

by Enrico Carlon (KU Leuven), Chair of FPSP XIII

The summer school FPSP addresses an audience of PhD students and young post-docs who wish to broaden their horizons in the field of Statistical Physics. The school offers a series of reviews on subjects of current interest from traditional Physics settings towards applications in Biology, Ecology, Evolution, Complex Systems or Finance. Still, the school keeps "fundamental problems" in its name to stress that, even in the most "exotic" modern applications, the depth of questioning and problem-solving stay related to the statistical mechanics of Maxwell, Boltzmann and Gibbs and later the tone-setting Dutch school of the 20th century. For an historical overview of FPSP, see: http://itf.fys.kuleuven.be/fpspxiii/.

▾ After having been organized in the Netherlands, Poland, Norway and Germany, FPSP moved to Belgium in 2005 where it has been held twice in a former Franciscan monastery in the beautiful setting "La Foresta" surrounded by large woods in the neighborhood of Leuven. The next and 13th edition is scheduled for June 2013 in the same venue.

Interview with Eddie Cohen

Reported by Joseph Indekeu (KU Leuven)

What has driven you to create a summer school? How did that happen?

In the fall of 1957, after obtaining my PhD degree with Professor Jan de Boer at the University of Amsterdam, I left for a postdoctoral position with Professor George E. Uhlenbeck (GU) in the University of Michigan at Ann Arbor, Michigan. This was followed by another year with Professor Theodore H. Berlin (TB) at the Johns Hopkins University in Baltimore, Maryland. Those two years in the USA have been crucial for my scientific career and in particular for the conception of a Summer school in Statistical Mechanics in the Netherlands. The first postdoctoral year with Uhlenbeck was a revelation for me. He realized rather quickly that I missed any scientific self-confidence, as I overheard him say one day to Berlin, when the latter visited him. However, convinced that I had a unique chance of realizing my desire to work on fundamental problems in Statistical Mechanics with "Mr Statistical Mechanics", I concentrated during my two years in the USA not on producing many publications – in fact I had none – but to learn as much as I could about this then very Dutch field of Physics from some of its major contributors.

Thus every day I walked with GU from our adjacent offices to the Michigan Union for lunch, asking him many questions that occurred to me about Statistical Mechanics and in particular about the problem he had given to me to solve. This concerned many aspects of the systematic generalization of the fundamental Boltzmann Equation for a dilute gas to denser gases, which would lead to a systematic expansion of the transport coefficients (such as the viscosity of a gas) in powers of the density of that gas, similar to the virial (density) expansion of the thermodynamic properties, such as the pressure, of a gas in thermal equilibrium. A seminal procedure to achieve this in a recursive way had been proposed by the Russian mathematical physicist Nicolai N. Bogolubov in 1944 and had gained very considerable attention, in particular by the advocacy of GU. This involved as a first and major step the generalization of the Boltzmann equation from binary collisions only, in a systematic way to include the effects of three, four, five, etc particle collisions. Many questions related to this fulfillment of "Boltzmann's dream" I could discuss with GU and later with TB during my USA stay. I should add, that during my stay in the USA I met, through GU and TB, many of the leading scientists working on the foundations of Statistical Mechanics. After my return to the Netherlands in 1959, I continued this work started with GU, all the while stimulated by him with very warm and encouraging letters. However, after a while, the paralyzing, self-confidence-demolishing thought crept in on me, that no matter what progress I would make, it would almost certainly have been done already, bigger and better at that, in the USA. I also realized that this was probably not just me, but the same for many colleagues in Europe, who must have had similar difficulties.

Then it occurred to me that, if I could introduce in Europe a similar stimulation as I had encountered in the USA, this could help remedy this paralysis. Then I remembered, that in the 1930's GU had organized a yearly Summer school in Ann Arbor, inviting there many of the foremost physicists from the then leading European continent for lectures. Thus I would have to use my familiarity with the American Statistical Mechanicians and invite many of them to lecture at this Summer school. That would give us Europeans the opportunity of getting to know and talk to them, a chance to demystify their achievements and create a small Marshall-like plan to revive Science, or at least Statistical Mechanics, in Europe.

▲ In FPSP XII (2009) about 85 participants mainly from Europe, but also from non-European countries, took part. Besides lectures and seminars, which occupy 5 hours during the day, there is also ample time for discussions and for practicing physical activities (tennis, football, volleyball, hiking, ...).

A great idea, but how could you finance it?

At that time, there was, in 1960, not long after the end of World War II, also a very forward-looking government Organization in the Netherlands: NUFFIC (Netherlands Universities Foundation For International Cooperation) under the imaginative and stimulating leadership of a former Chief Resident in Indonesia: general director Mr. H.G. Quik. He and I got along very well and, most importantly, NUFFIC made the Summer school financially possible. Later, also The Rockefeller University in New York made contributions to the Summer school, not only by providing lecturers (GU, Mark Kac, Kenneth M. Case and myself) but also by visits of two Presidents and by financial support.

All Summer schools were held then in The Netherlands, with the exception of one, in 1977, in Poland, co-organized with Professor Wladek Fiszdon, to stimulate also Eastern European countries. That this School has lasted already 50 years is, for sure, beyond any expectations, but by selecting as speakers not only leaders in their fields but also good lecturers as well as very capable and charming secretaries, may well have contributed to its longevity.

I remained active in organizing, lecturing and editing the Proceedings of the School: "Fundamental Problems in Statistical Mechanics" for about 25 years, till 1985. After that, Professor Henk van Beijeren took over when the School, after once being held in Norway, moved to Altenberg (Germany) and after that Professor Joseph Indekeu in Leuven (Belgium) led the School till today.

Before I conclude this short survey, I would like to mention one, to me very important aspect, of the Summer school, which was inspired by the founder of Dutch Statistical Mechanics, Paul Ehrenfest. As GU, who was one of Ehrenfest's students, told me, at his weekly Colloquium Ehrenfestii, which he led every Wednesday evening in Leiden, the students did not only have the obligation to be present, but had to ask a question, whenever they had not understood something. Ehrenfest checked this by selecting students, whom he asked whether they had indeed understood what had been said and if they could not answer this properly, it would put them in an embarrassing position, since they had not asked a question about it. Although effective, it was clearly not the way to proceed during the Summer school. Therefore, I put myself on the front row in the lecture room and when the lecturer made a statement, in my opinion, with a logical gap in his presentation, I asked a question for more explanation. This, to the great satisfaction of the students who had not understood the argument either, but had been afraid to ask a "stupid question". I realize that these interruptions of their presentations may not always have been appreciated by the lecturers. I would like to think, though, that they did contribute to the success of the Summer school, as its Proceedings. ■

Opinion: Can we close the gap?

Herman C. W. Beijerinck,
Eindhoven University of Technology - h.c.w.beijerinck@tue.nl

Academia and industry each have their own agenda. Curiosity-driven fundamental and applied research with scientific papers as output is the mainstay of universities. Goal-oriented research aiming at patents, prototypes and products is the realm of industry. However, on the work floor, there is a lack of communication and understanding between these two communities.

How can we establish a rewarding partnership between these two parties? Can we fill the gap between academia and industry in a way that attracts motivated and talented young engineers? Yes, we can, as we have experienced at Eindhoven University of Technology. We have extended the 1D space of science-based PhD's to a 2D space with a goal-oriented PhD-on-design as a new axis, orthogonal to the existing one.

New graduate programme

The game starts in a two-year graduate programme beyond the M.Sc., aimed at training talented engineers with a love for goal-oriented projects for a future career in industry (www.sai.tue.nl/dti) or health care (www.smpee.tue.nl). This designer course has a broad basis, with emphasis on both personal skills and a combination of applying modeling tools and practical experience. A one-year project in industry is an essential part of the programme, giving hands-on experience with tight-loop feed-back from university. Here, the students apply all skills learned to achieve their goal, based on efficient project planning. Based on the mutual trust established in these 12 months, the decision of extending this project by 2 ½ years into a PhD-on-design is easily taken. Typically 25% of the students from the designer course continue their career in this way.

Training graduate students in the void between academia and industry

Measuring quality

Efficient reporting is essential in industry to debrief oneself, to keep the team members informed, and to avoid pitfalls in interpreting the results. These technical notes – mostly confidential – are the basis for writing the thesis at the end of the 2 ½ year period. The thesis contains the story line of the design work, without reporting all the details that would put the company at risk for loss of proprietary information. The five members of the core committee - that take part in the final public defense of the thesis - do obtain all the technical notes as auxiliary information. However, they sign a Non-Disclosure Agreement for access to these documents.

Patents, prototypes and process windows – the three P's - are the measure of quality. Depending on the field of interest, most students end up as the (co)inventor of two to five patents and/or the 'author' of a functional prototype or process. If papers are published, one should consider this as 'collateral damage'!

Scouting new talent

We argue that a PhD-on-design is an important innovation in physics education. By training graduate students in the void between academia and industry we combine the better of two worlds. In addition, we capture talented students for graduate training who would otherwise be lost. By describing PhD projects in a 2D space with a science-based axis and a goal-oriented axis, we can identify their nature as a linear combination of these basis vectors. This allows us to judge the quality of the work on a realistic basis, avoiding the pitfall of looking only at journal papers as a measure of success.

The close contacts with industry can be a source of inspiration for the academic staff and undergraduate teaching. University professors end up in an inspiring dual role as advisor and consultant. For the company or hospital, the PhD-on-design results in out-of-the-box input to innovation. ■

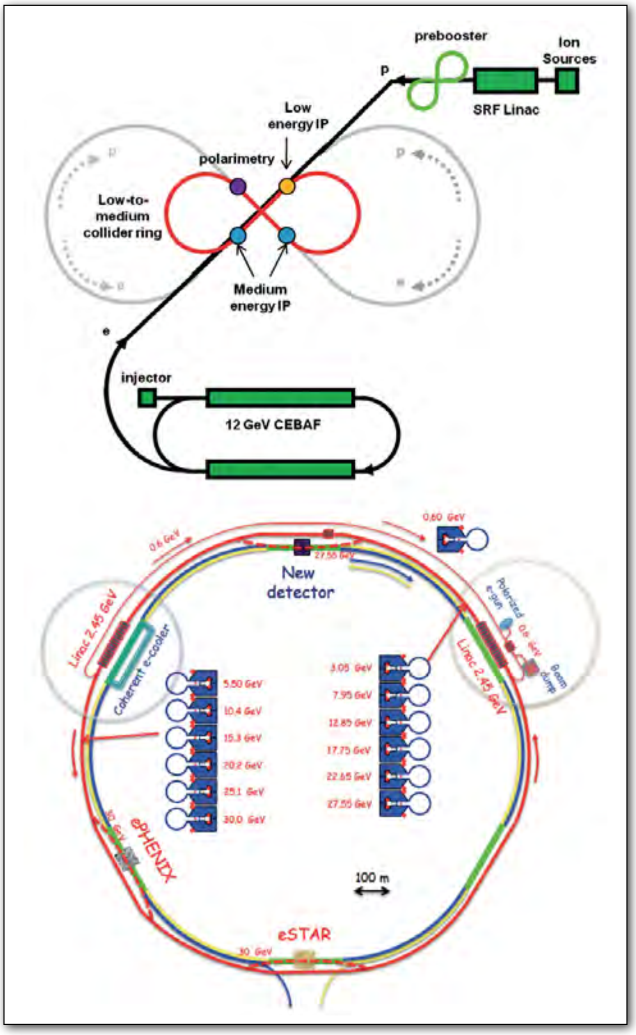
Highlights from European journals

NUCLEAR PHYSICS

Nuclear physics in an electron-ion collider

Quarks and gluons are the fundamental constituents of most of the matter in the visible Universe; Quantum Chromodynamics (QCD), a relativistic quantum field theory based on color gauge symmetry, describes their strong interactions. The understanding of the static and dynamical properties of the visible strongly interacting particles - hadrons - in terms of quarks and gluons is one of the most fascinating issues in hadron physics and QCD. In particular the exploration of the internal structure of protons and neutrons is one of the outstanding questions in experimental and theoretical nuclear and hadron physics. Impressive progress has been achieved recently.

▾ Possible realizations of a medium-energy EIC: MEIC at Jefferson Lab (top) and eRHIC at Brookhaven National Lab (bottom)



The paper, clearly and concisely, addresses several of the issues related to the microscopic structure of hadrons and nuclei:
(i) The three–dimensional structure of the nucleon in QCD, which involves the spatial distributions of quark and gluons, their orbital motion, possible correlations between spin and intrinsic motion;
(ii) The fundamental colour fields in nuclei (nuclear parton densities, shadowing, coherence effects, colour transparency);
(iii) The conversion of colour charge to hadrons (fragmentation, parton propagation through matter, in–medium jets).
The conceptual aspects of these questions are briefly reviewed and the measurements that would address them are discussed, with emphasis on the new information that could be obtained with experiments at an electron-ion collider collider (EIC). Such a medium–energy EIC could be realized at Jefferson Lab after the 12 GeV upgrade (MEIC), or at Brookhaven National Lab as the low–energy stage of eRHIC. ■

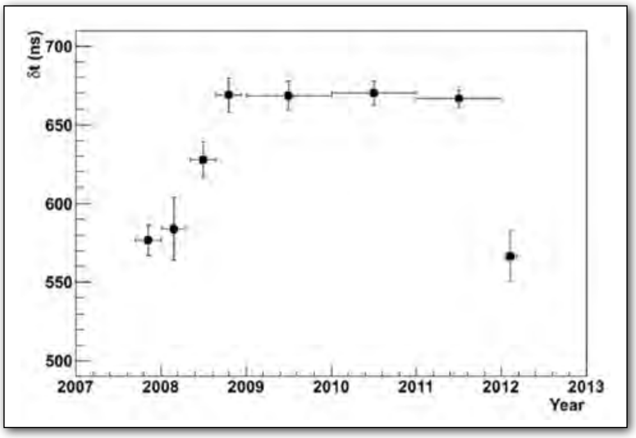
■ **A. Accardi**, **V. Guzey**, **A. Prokudin** and **C. Weiss**, 'Nuclear physics with a medium-energy Electron-Ion Collider', *Eur. Phys. J. A* **48**, 92 (2012)

PARTICLE PHYSICS

Time shift in the OPERA setup

The halls of the INFN Gran Sasso Laboratory (LNGS) were designed by A. Zichichi and built in the 1980s, oriented towards CERN for experiments on neutrino beams. In 2006, the CERN Neutrinos to Gran Sasso (CNGS) beam started the search for tau-neutrino appearances in the muon-neutrino beam produced at CERN, using the OPERA detector built for this purpose.

▾ Distribution of the $\delta t = t_{LVD} - t^*_{OPERA}$ for corrected events. All the events of each year are grouped into one single point with the exception of 2008, which is subdivided into three periods.



In 2011, OPERA reported that the time of flight (TOF) of neutrinos measured on the 730km between CERN and LNGS was ~ 60ns shorter than that of light. Since the synchronisation of two clocks in different locations is a very delicate operation and a technical challenge, OPERA had to be helped by external experts in metrology. This paper presents a much simpler and completely local check, by synchronising OPERA and LVD. Both detectors at LNGS are about 160m apart along the axis of the so-called "Teramo anomaly." This structural anomaly in the Gran Sasso massif, established by LVD many years ago, lets through high-energy horizontal muons at the rate of one every few days, penetrating both experiments. The LVD-OPERA TOF measurement shows an offset of OPERA comparable with the claimed superluminal effect during the period in which the corresponding data were collected, and no offset in the periods before and after that data taking (when OPERA had corrected equipment malfunctions), as shown in the figure. The result of this joint analysis is the first quantitative measurement of the relative time stability between the two detectors and provides a check that is completely independent of the TOF measurements of CNGS neutrino events, pointing to the existence of a possible systematic effect in the OPERA neutrino velocity analysis. ■

■ **N.Yu. Agafonova** plus **19 co-authors from LVD collaboration** and **70 from OPERA collaboration**, 'Determination of a time shift in the OPERA setup using high-energy horizontal muons in the LVD and OPERA detectors', *Eur. Phys. J. Plus* **127**, 71 (2012)

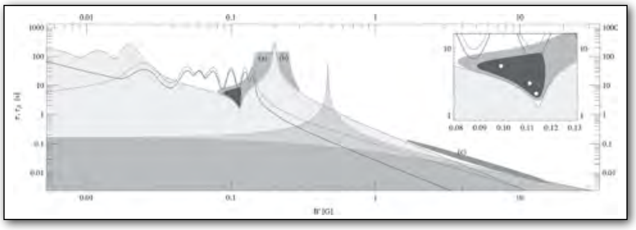
PARTICLE PHYSICS

Neutrons escaping to a parallel world?

An anomaly in the behaviour of ordinary particles may point to the existence of mirror particles that could be candidates for dark matter responsible for the missing mass of the universe. In the present paper, the authors hypothesised the existence of mirror particles to explain the anomalous loss of neutrons observed experimentally. The existence of such mirror matter had been suggested in various scientific contexts some time ago, including in the search for dark matter.

The authors re-analysed the experimental data obtained at the Institut Laue-Langevin, France. It showed that the loss rate of very slow free neutrons appeared to depend on the direction and strength of the magnetic field applied.

The authors believe it could be interpreted in the light of a hypothetical parallel world consisting of mirror particles. Each neutron would have the ability to transition into its invisible mirror twin, and back, oscillating from one world to the other. The probability of such a transition happening was predicted to be sensitive to the presence of magnetic fields, and could be detected experimentally.



▲ Anomalous loss of neutrons observed experimentally

This oscillation could occur within a timescale of a few seconds, according to the paper. The possibility of such a fast disappearance of neutrons—much faster than the ten minute long neutron decay—is subject to the condition that the earth possesses a mirror magnetic field that could be induced by mirror particles floating around in the galaxy as dark matter. Hypothetically, the earth could capture the mirror matter via some feeble interactions between ordinary particles and those from parallel worlds. ■

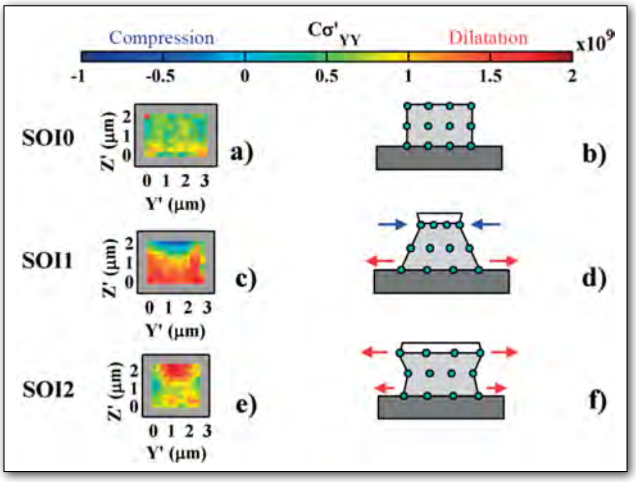
■ **Z. Berezhiani** and **F. Nesti**, 'Magnetic anomaly in UCN trapping: signal for neutron oscillations to parallel world?', *Eur. Phys. J. C* **72**, 1974 (2012)

MATERIAL SCIENCE

2D Raman mapping of stress and strain in Si waveguides

In this work, we characterized the mechanical stress of strained silicon waveguides by micro-Raman spectroscopy. We performed accurate measurements on the waveguide facet by using a confocal Raman microscope. The silicon-on-insulator waveguide is strained by depositing thin stressing silicon nitride (SiN) overlayers. The applied stress is varied by using different deposition techniques. By investigating the waveguides facets and modeling the measured Raman shifts, the local stress and strain are extracted. Thus, 2D

▼ Measured stress maps and lattice deformation sketches for waveguides: (a)-(b) without cladding (SOI0), (c)-(d) with tensile-stressing cladding (SOI1), (e)-(f) with compressive-strassing cladding (SOI2°. The arrows show the type of observed stress.



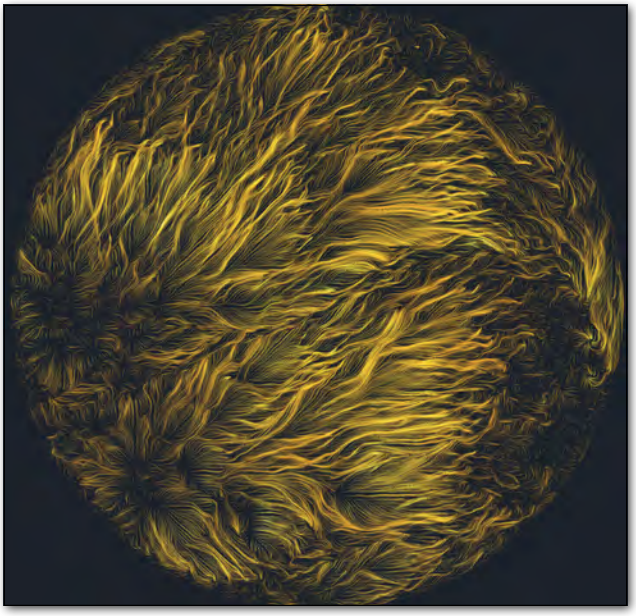
maps of stress distribution as a function of SiN deposition parameters are drawn showing different strain distributions depending on the deposition technique. Moreover, the results show a relevant role played by the buried oxide layer, which strongly affects the waveguides final stress. Hence, the combined actions of SiN and buried oxide layers deform the whole silicon core layer and cause an inhomogeneous strain distribution in the waveguides.
The strain inhomogeneity is fundamental to enable second order nonlinear optical devices because it breaks the silicon centro-symmetry yielding a huge second order nonlinear susceptibility ($\chi^{(2)}$). As we demonstrate in *Nature Mater.* **11**, 148 (2012), a $\chi^{(2)}$ of several tens of picometers per volt is observed and a relation between the $\chi^{(2)}$ values and the strain inhomogeneity and magnitude is revealed. Particularly, the largest conversion efficiency is observed in the waveguides where the micro-Raman spectroscopy shows the highest deformation. Currently, no explicit theory relating the strain with the $\chi^{(2)}$ exists. Thus, the 2D micro-Raman maps could be a valuable tool for experimental confirmation of future theories. ■

■ **F. Bianco**, **K. Fedus**, **F. Enrichi**, **R. Pierobon**, **M. Cazzanelli**, **M. Ghulinyan**, **G. Pucker** and **L. Pavesi**, 'Two-dimensional micro-Raman mapping of stress and strain distributions in strained silicon waveguides which show second order optical nonlinearities', *Semicond. Sci. Technol.* **27**, 085009 (2012)

LIQUID PHYSICS

Turbulent convection at the core of fluid dynamics

Buoyant convection of a fluid subjected to thermal differences is a classical problem in fluid dynamics. Its importance is compounded by its relevance to many natural and technological phenomena. For example, in the Earth atmosphere, the study of thermal convection allows us to do weather forecasts and, on larger time and length-scales, climate calculations. In the oceans, where there are differences in temperature and salinity, turbulent convection drives deep-water currents. Geology and astrophysics are other areas where thermal convection has great impact. The simplest and most useful convection system is the Rayleigh-Bénard setup: a fluid in a container heated from below and cooled from above. In this classical system, the flow properties are determined by the scale and geometry of the container, the material properties of the fluid, and the temperature difference between top and bottom. The crux of the problem is how to determine the rate of heat transfer in a given condition. In this Colloquium paper, the authors review the recent experimental, numerical and theoretical advances in turbulent Rayleigh-Bénard convection. Particular emphasis is given to the physics and structure of the thermal and velocity boundary layers, which play a crucial role in governing the turbulent transport of heat and momentum in highly turbulent regimes. The authors moreover discuss some important extensions of Rayleigh-Bénard convection, such as the so-called non-Oberbeck-Boussinesq effects and address convection with phase changes. ■



▲ Visualization (view from the top) of streamwise flow structures inside the boundary layer

■ **F. Chillà** and **J. Schumacher**, 'New perspectives in turbulent Rayleigh-Bénard convection', *Eur. Phys. J. E* **35**, 58 (2012)

STATISTICAL PHYSICS

Spurious switching points in traded stock dynamics

A selection of biased statistical subsets could yield an inaccurate interpretation of market behaviour and financial returns.
In the present paper, the authors rebuff the existence of power laws governing the dynamics of traded stock volatility, volume and inter-trade times at times of stock price extrema, by demonstrating that what appeared as "switching points" in financial markets trends was due to a bias in the interpretation of market data statistics.
A prior study based on conditional statistics suggested that the local maxima of volatility and volume, and local minima of inter-trade times are akin to switching points in financial returns, reminiscent of critical transition points in physics. These local extrema were thought to follow approximate power laws.
To disentangle the effect of the conditional statistics on the market data trends, the authors compare stock prices traded on the financial market with a known statistical model of price featuring simple random behaviour, called Geometrical Brownian Motion (GBM). They demonstrate that "switching points" occur in the GBM model, too.

▲ Trends in stock prices dynamics are notoriously difficult to interpret.

The authors find that, in the case of volatility data, the misguided interpretation of switching points stems from a bias in the selection of price peaks that imposes a condition on the statistics of price change, which skews its distributions. Under this bias, switching points in volume appear naturally due to the volume-volatility correlation. For the intertrade times, they show that extrema and power laws result from the bias introduced in the format of transaction data. ■

■ **V. Filimonov** and **D. Sornette**,
'Spurious trend switching phenomena in financial markets', *Eur. Phys. J. B* **85**, 155 (2012)

QUANTUM PHYSICS

Disentangling information from photons

This work describes greater chances of accessing more reliable information on applications in quantum computing and cryptography. The authors have found a new method of reliably assessing the information contained in photon pairs used for applications in cryptography and quantum computing. The findings are so robust that they enable access to the information even when the measurements on photon pairs are imperfect. The authors focus on photon pairs described as being in a state of quantum entanglement: *i.e.*, made up of many superimposed pairs of states. This means that these photon pairs are intimately linked by common physical characteristics such as a spatial property called orbital angular momentum, which can display a different value for each superimposed state.

They rely on a tool capable of decomposing the photon pairs' superimposed states onto the multiple dimensions of a Hilbert space, which is a virtual space described by mathematical equations. This approach allows them to understand the level of the photon pairs' entanglement.

It is shown that the higher the degree of entanglement, the more accessible the information that photon pairs carry. This means that generating entangled photon pairs with a sufficiently high dimension—that is with a high enough number of decomposed photon states that can be measured—could help reveal their information with great certainty.

As a result, even an imperfect measurement of photons' physical characteristics does not affect the amount of information that can be gained, as long as the level of entanglement was initially strong. These findings could lead to quantum information applications with greater resilience to errors and a higher information density coding per photon pair. They could also lead to cryptography applications where fewer photons carry more information about complex quantum encryption keys. ■

▼ Disentangling information from photons (Image: © Peter Nguyen, iStockphoto)

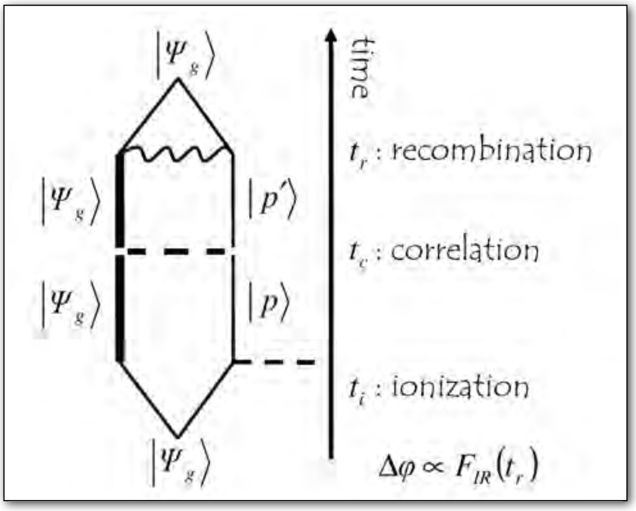
■ **F.M. Miatto**, **T. Brougham** and **A.M. Yao**,
'Cartesian and polar Schmidt bases for down-converted photons', *Eur. Phys. J. D* **66**, 183 (2012)

ATOMIC AND MOLECULAR PHYSICS

Attosecond control of electron correlation

Electron correlation is ubiquitous in one-photon ionization and its time reverse, photo-recombination. It redistributes transition probabilities between open ionization channels in an atom or molecule. The photo-ionization and photo-recombination cross-sections are commonly assumed to be a fixed property of the target, impervious to experimental manipulation.

This article develops an analytical model of correlated photo-ionization and photo-recombination in the presence of a strong, near-infrared (IR) laser field. It shows that the characteristic time of the electron-electron interaction differs slightly from the time of the ionization (or recombination). As a result, correlation channels acquire an additional phase, proportional to the instantaneous IR laser electric field. Interferences between the direct and correlation channels then lead to either suppression or enhancement of overall cross-sections. These interferences are under direct experimental control and can be used to adjust probabilities of ionization and recombination.



▲ The photo-recombination dipole phase $\Delta\varphi$ in a correlation-assisted channel is proportional to electric field strength F_{IR} at the time of recombination t_r.

Numerical estimates suggest that the desired control conditions are attainable in strong-field experiments. If the prediction is confirmed by experiment, it will open new avenues for strong-field investigations of electron correlation and for the design of high-harmonic radiation sources. ■

■ **S. Patchkovskii**, **O. Smirnova** and **M. Spanner**, 'Attosecond control of electron correlations in one-photon ionization and recombination', *J. Phys. B: At. Mol. Opt. Phys.* **45**, 131002 (2012)

LIQUID PHYSICS

The **"inertia of heat"** concept revisited

What is the general relativistic version of the Navier-Stokes-Fourier dissipative hydrodynamics? Surprisingly, no satisfactory answer to this question is known today. Eckart's early solution [Eckart, *Phys. Rev.* **58**, 919 (1940)], is considered outdated on many grounds: the instability of its equilibrium states, ill-posed initial-value formulation, inconsistency with linear irreversible thermodynamics, *etc.* Although alternative theories have been proposed recently, none appears to have won the consensus.

This paper reconsiders the foundations of Eckart's theory, focusing on its main peculiarity and simultaneous difficulty: the "inertia of heat" term in the constitutive relation for the heat flux, which couples temperature to acceleration. In particular, it shows that this term arises only if one insists on defining the thermal diffusivity independently of the gravitational field. It is argued that this is not a physically sensible approach, because gravitational time dilation implies that the diffusivity actually varies in space. In a nutshell, where time runs faster, thermal diffusion also runs faster. It is proposed that this is the physical meaning of the "inertia of heat" concept, and that such an effect should be expected in any theory of dissipative hydrodynamics that is consistent with general relativity. ■

■ **M. Smerlak**, 'On the inertia of heat', *Eur. Phys. J. Plus* **127**, 72 (2012)

BIOPHYSICS

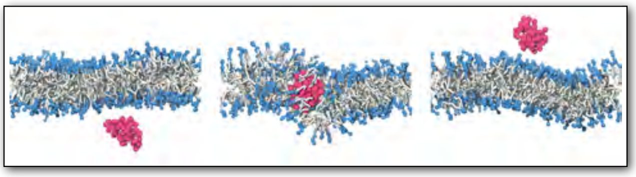
Translocation of polymers through lipid bilayers

Lipid bilayers emerge by self-organization of amphiphilic molecules and are the essential component of membranes of living cells. An important task of them is the selective exchange of substances between the cell and its environment. This becomes particularly interesting for delivering foreign molecules and RNA into the cell. In the classical view of cell biology static structures such as pores and channels formed by specific proteins control the translocation of molecules.

In this work we show that there exists a straightforward mechanism for translocation of polymers through lipid bilayers if the monomers of the chain show a certain balance of hydrophobic and hydrophilic strength. Using the bond fluctuation method with explicit solvent to simulate the self-organized lipid bilayer and the polymer chain we show that the chain is adsorbed by the bilayer at a critical hydrophobicity of the monomers. At this point all monomers have an intermediate degree of hydrophobicity, which is large enough to overcome the insertion barrier of the ordered lipids, but still small enough to avoid trapping in the core of the bilayer. In a narrow range around this critical hydrophobicity the chain can almost freely penetrate through the model membrane whose hydrophobic core becomes energetically transparent here. Our simulations also allow calculate the permeability of the membrane with respect to the solvent. We show that the permeability is strongly increased close to the critical hydrophobicity suggesting that here the perturbation of the membrane patch around the adsorbed chain is highest. ■

■ **J-U. Sommer**, **M. Werner** and **V. A. Baulin**, 'Critical adsorption controls translocation of polymer chains through lipid bilayers and permeation of solvent', *EPL* **98**, 18003 (2012)

▼ Snapshots of a polymer chain diffusing through the bilayer at the critical hydrophobicity. Strong perturbations of the lipid ordering can be observed during the adsorption/translocation event (middle).



NUCLEAR PHYSICS

High intensity ^{6}He beam production

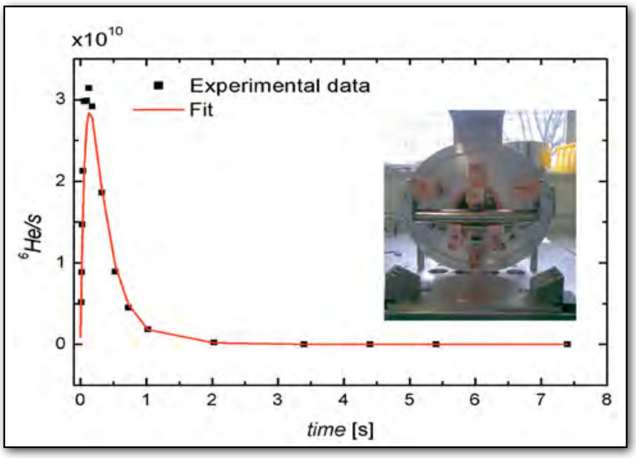
Nuclear structures of short-lived radioisotopes are nowadays investigated in large-scale facilities based on in-flight fragmentation or isotope separation online (ISOL) methods. The ISOL technique has been constantly extended at CERN-ISOLDE, where 1.4GeV protons are exploited by physicists to create radioisotopes in thick materials; these exotic nuclei are released and pumped online into an ion source, producing a secondary beam which is further selected in a magnetic mass spectrometer before post-acceleration.

Ten years ago a proposal to inject suitable ISOL beams into the CERN accelerator complex and to store these isotopes in a decay ring with straight sections was proposed for a "*β-beam* facility"; intense sources of pure electron neutrinos - emitted when such isotopes decay - are directed towards massive underground detectors for fundamental studies such as observation of neutrino flavour oscillations and CP violation.

Our paper reports on the experimental production of the anti-neutrino emitter ^{6}He. We use a two-step reaction in which the proton beam interacts with a tungsten neutron spallation source. The emitted neutrons intercept a BeO target to produce ^{9}Be(n,a)^{6}He reactions. The neutron field was simulated by Monte-Carlo codes such as Fluka and experimentally measured. The large predicted ^{6}He production rates were also experimentally verified. Fast ^{6}He diffusion, driven by the selection of a suitable BeO material, could be demonstrated, leading to the highest ^{6}He beam rates ever achieved at ISOLDE. These results provide a firm experimental confirmation that the *β-beam* will be able to deliver enough anti-neutrino rates using a neutron spallation source similar to ISIS-RAL (UK). This work is now being completed by the experimental validation of the ^{18}Ne neutrino source design. ■

■ **T. Stora** and **11 co-authors**,
'A high intensity ^{6}He beam for the β-beam neutrino oscillation Facility', *EPL* **98**, 32001 (2012)

▼ ISOLDE production unit equipped with a spallation neutron source along the target oven. Fast release of ^{6}He anti-neutrino emitters, produced by a BeO target with the CERN's proton beam.

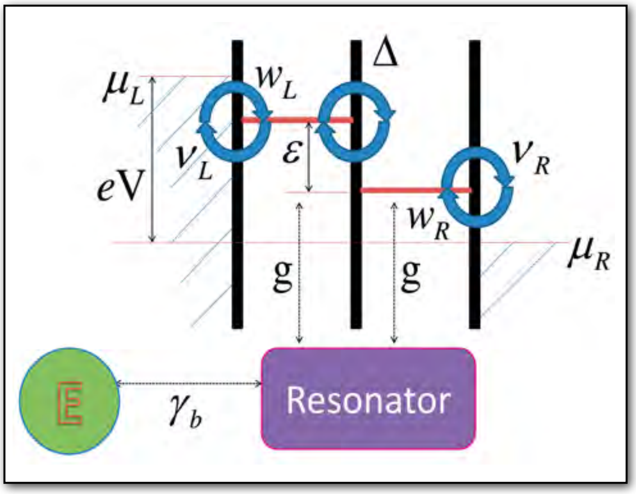


CONDENSED MATTER

Improved quantum information motion control

A new model simulates closer control over the transport of information carrying electrons under specific external vibration conditions. The present article developes a new method for handling the effect of the interplay between vibrations and electrons on electronic transport, which could have implications for quantum computers due to improvements in the transport of discrete amounts of information, known as qubits, encoded in electrons.

The authors create an electron transport model to assess electrons' current fluctuations based on a double quantum dot (DQD) subjected to quantized modes of vibration, also known as phonons, induced by a nanomechanical resonator. Unlike previous studies, this work imposes arbitrary strong coupling regimes between electrons and phonons.



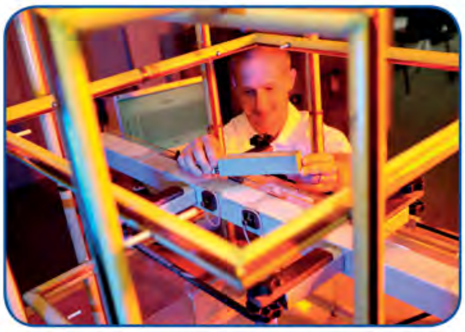
▲ Sketch map of the double quantum dot (two horizontal lines) coupled with the nanomechanical resonator (rectangle).

They successfully control the excitations of the phonons without impacting the transport of quantum information. They decouple the electron-phonon interaction by inducing resonance frequency of phonons. When the energy excess between the two quantum dots of the DQD system is sufficient to create an integer number of phonons, electrons can reach resonance and tunnel from one quantum dot to the other.

As electron-phonon coupling becomes even stronger, the phenomenon of phonon scattering represses electron transport and confines them, suggesting that tuning the electron-phonon coupling, could make a good quantum switch to control the transport of information in quantum computers. ■

■ **C. Wang**, **J. Ren**, **B. Li** and **Q-H. Chen**,
'Quantum transport of double quantum dots coupled to an oscillator in arbitrary strong coupling regime',
Eur. Phys. J. B **85**, 110 (2012)

Magnetic Field Instrumentation



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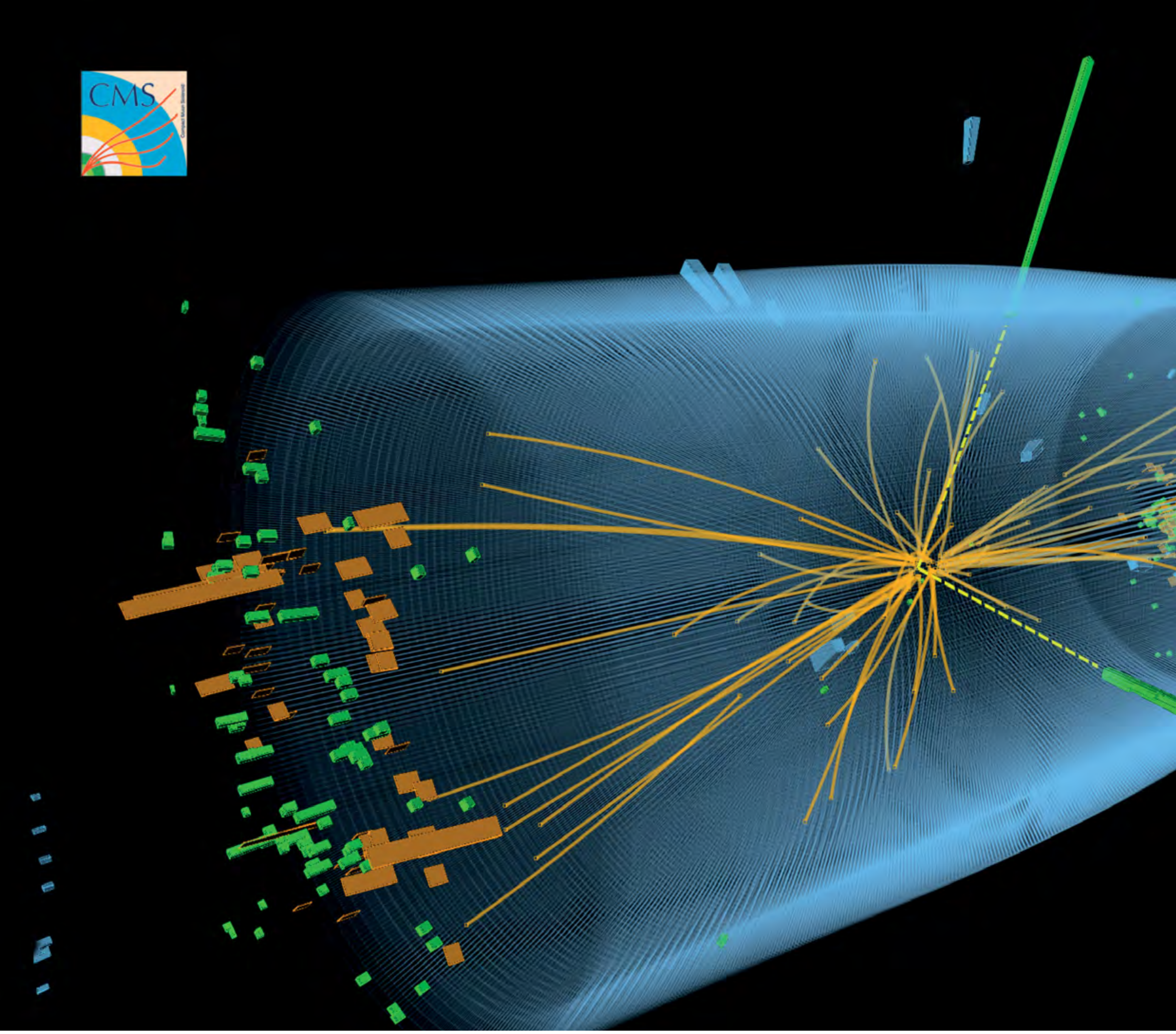


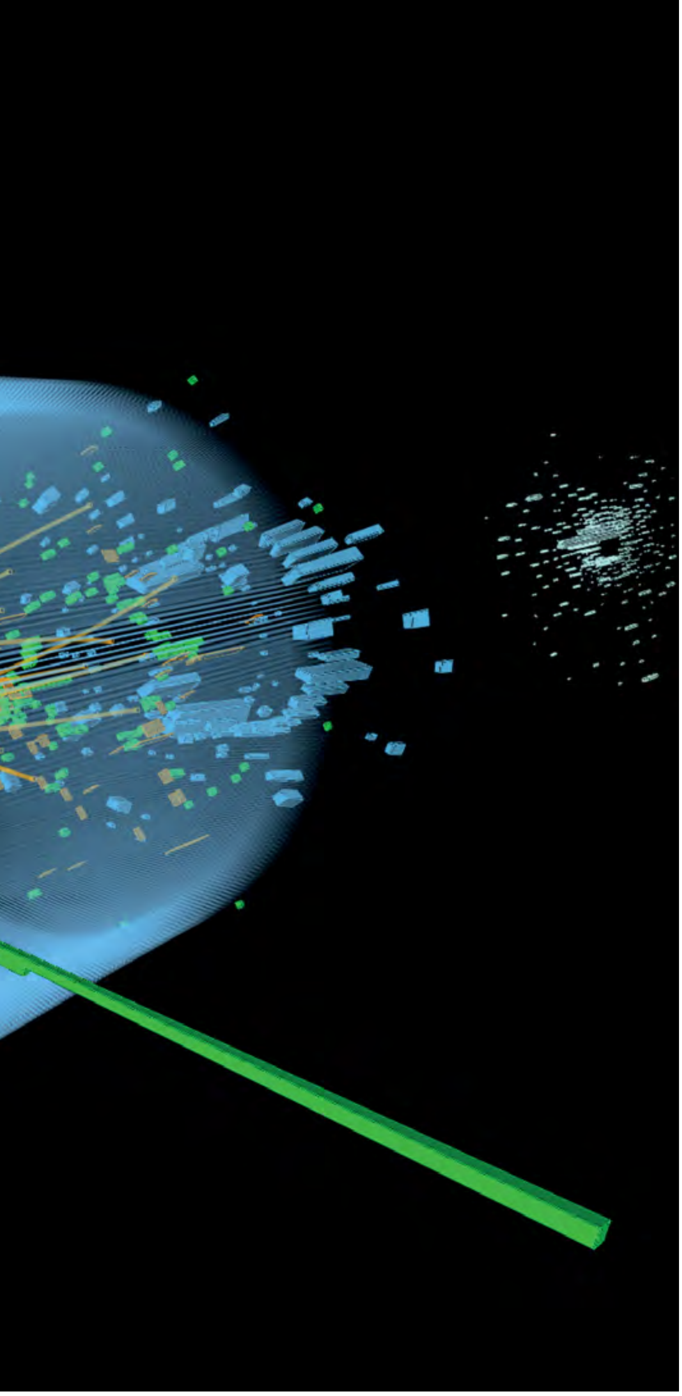
The seven months that changed physics

The discovery of the Higgs Boson and its implications for High Energy Physics

■ **Guido Tonelli** - CERN, Geneva, Switzerland;
■ University of Pisa and INFN Sezione di Pisa, Italy - DOI: 10.1051/epn/2012501

Researchers of the ATLAS and CMS experiments at CERN, have announced the discovery of a new particle whose characteristics seem to be consistent with the ones expected for the long sought Higgs boson. Are we there at last? And what could be the implications of this historical discovery?

The Higgs boson is an unstable particle, living for only the tiniest fraction of a second. But it plays a major role in particle physics and in shaping the cosmos. The particle can be seen as a manifestation of an invisible field that fills every corner of our universe, assigning a distinctive mass to each elementary particle through its interaction with the field. Heavy particles, like super-massive top quarks, experience strong couplings with the Higgs field, while massless particles, like photons, can fly through it unaffected. As a consequence of the mechanism, the chaotic ingredients of the early universe at a certain moment started eventually



◂ The Higgs boson at last? Event recorded by the CMS detector in 2012

to attract one another and clump into atoms, gas, galaxies, planets and people. It is not simply a new elementary particle, it is the real cornerstone of the Standard Model (SM), a highly successful theory that provides an accurate description of matter and of its interactions.

The Standard Model and the Higgs Boson

The SM considers matter as composed by quarks and leptons and describes their interactions through the exchange of force carriers: the photon for electromagnetic interactions, the W and Z bosons for weak interactions, and the gluons for strong interactions. The SM is a simple and elegant theory that brings together quantum mechanics and special relativity, the two major pillars of 20th century physics. It explains a huge amount of data using only 19 parameters and yielded an incredibly precise set of predictions. A key component of the SM is the Higgs particle. Back in 1964, Robert Brout and Francois Englert in Brussels and, independently, Peter Higgs in Edinburgh (Fig.1) proposed a mechanism called spontaneous symmetry breaking. It allowed to generate large masses for the W and Z bosons carrying the weak interactions, while the photon remained massless [1,2,]. The absolutely innovative approach consisted in getting these results into a framework in which the elegant symmetry of the underlying gauge equations was fully preserved. The mechanism was based on a new scalar field, later named *H* after Peter Higgs, whose excitations can manifest themselves in a real spin 0 particle. The field can also provide mass to the fundamental fermions, quarks and leptons, through the so-called Yukawa interaction[1].

The Longest and Toughest Hunt Ever in Particle Physics

Physicists have been hunting the Higgs boson ever since the mid-1970s, when the SM gained widespread acceptance. The discovery of the elusive particle was among the highest priorities for several generations of experiments. The exact mass m_H, of the Higgs is not predicted by theory. General considerations suggest only that m_H should be smaller than ~1 TeV. Since the production cross-section, width and branching fractions in the various decay modes do depend strongly on the mass, the search in itself becomes extremely challenging. To make things even more complicated, the most promising decay modes are heavily contaminated by many sources of reducible and irreducible backgrounds due to known SM processes.

Since it was not observed in data, even the most sophisticated experiments preceding LHC were only able to produce limits on its mass. Over the past twenty years, direct searches for the Higgs boson have been carried out at the Large Electron Positron (LEP) collider, leading to a lower bound of m_H >114.4 GeV at 95% confidence level (CL), and at the Tevatron proton-antiproton collider, excluding the mass range between 162 and 166 GeV [3,4]. Precision electroweak measurements, not taking into account the results from direct searches, indirectly constrain the SM Higgs boson mass to be less than 158GeV.

The Large Hadron Collider (LHC) and its General-Purpose Detectors: ATLAS and CMS

The project of building the Large Hadron Collider (LHC) and its large general-purpose detectors was mostly driven by the goal of discovering the SM Higgs boson or alternative mechanisms for the electroweak symmetry breaking. The LHC (Fig.2) is the most powerful collider ever built. It is a gigantic accelerator equipped with thousand of superconducting magnets and accelerating cavities distributed in a 27 km tunnel, 100 m underground, close to Geneva.

[1] The Yukawa interaction was introduced to describe the strong nuclear force between nucleons, which are fermions, mediated by pseudoscalar pions. The same formalism has been used to describe the interaction between the massless fermions, quarks and leptons, and the Higgs scalar field.

In normal operation it accelerates about 1400 packets of particles, each one containing roughly 1.5×10^{11} protons, up to an energy of 3.5 (later 4.0) TeV per beam corresponding to a center-of-mass energy of 7 (8) TeV[2]. Squeezed packets of protons are brought to collisions every 50 ns in the interaction regions surrounded by the large detectors. ATLAS and CMS are modern, general-purpose detectors based on sophisticated tracking systems embedded in strong magnetic fields. State-of-the-art calorimeters cover a large fraction of the solid angle and are complemented by huge sets of muon detectors [5,6]. A complex system of trigger and data acquisition selects the most interesting events that are permanently recorded for offline analysis. A distributed system of computing, based on GRID technologies, has been developed to reconstruct, store and analyse the data. Thousands of physicists and engineers worked feverishly for many years to build these cathedrals of modern technologies. The efforts continue nowadays to maintain, operate and improve detectors and computing infrastructures, while physics results are continuously extracted from the analysis of the data. LHC started 7 TeV operations in spring 2010, at very low intensity, but the progress in the last two years have been such that, nowadays, the machine is capable to deliver, in a few hours, the same amount of data yielded in the whole first year of operation.

December 2011-July 1012: from the First Evidence to the Discovery

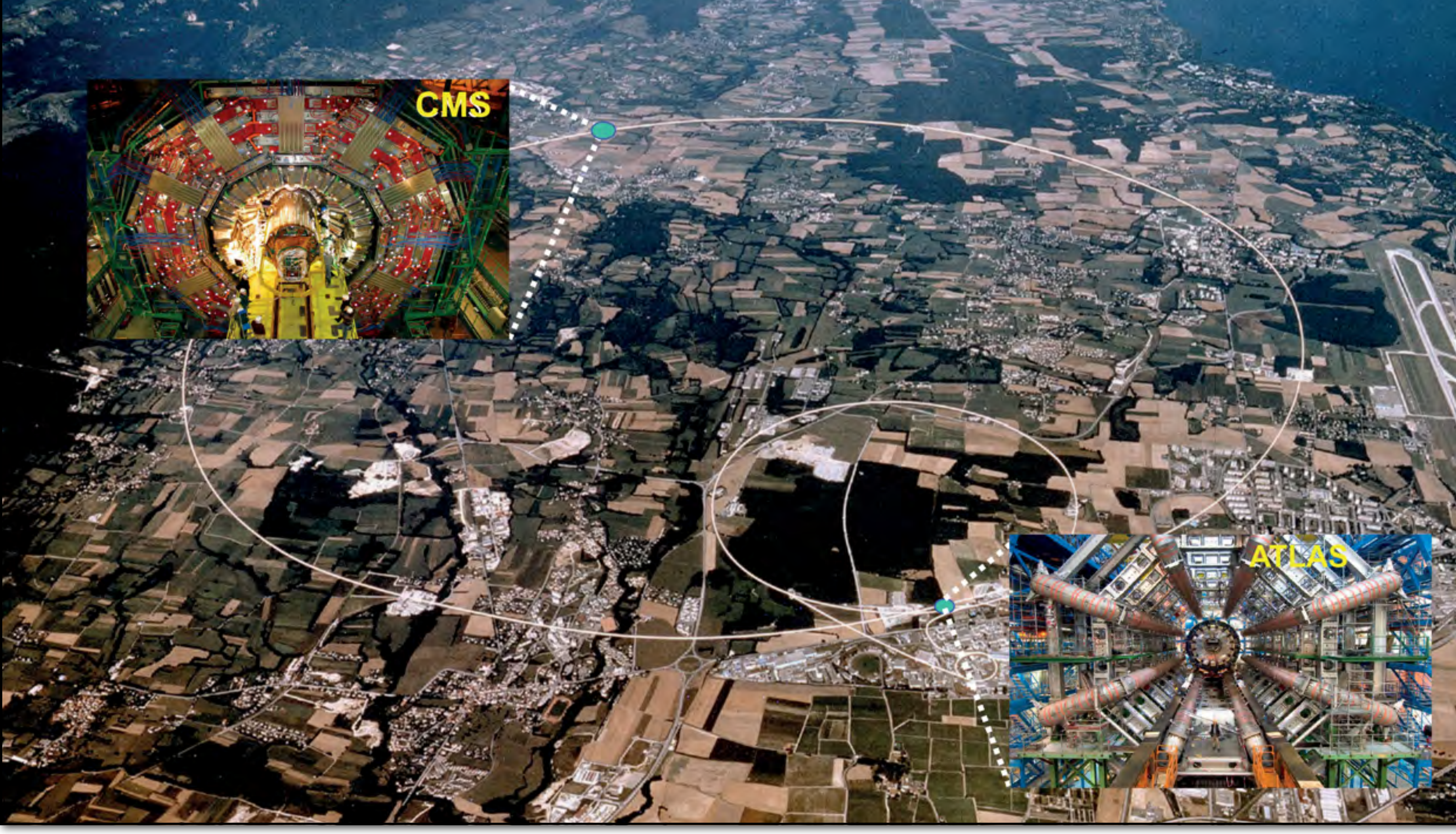
Thanks to the excellent performance of LHC, at the end of 2011 the experiments reached a key milestone. For the first time, the amount of data was large enough to perform a complete and exhaustive search of the SM Higgs in the full mass range. The preliminary analysis of these data yielded important results that were presented in a special seminar held at CERN on December 13th, 2011 [7,8]. Since the Higgs boson decays immediately into other particles, experiments can observe it only by measuring the products of its decays. ATLAS and CMS reported a complex set of studies using all major decay modes: pairs of W or Z bosons, pairs of b quarks, τ-leptons and photons. New exclusion limits, at 95% CL, were reported by each experiment between 600 and about 130 GeV. The striking news was that both experiments were not able to exclude the SM Higgs boson in the low mass region due to the presence of a narrow bump around 125 GeV. The excess was driven by the high-resolution channels, $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4$ leptons, and the two independent observations were fully consistent each other. Although the statistical significance of the observed excesses, 3.5 and 3.1 σ respectively for ATLAS and CMS, was not large enough to claim a discovery, this 'coincidence of signals' was un-precedented. Many physicists started thinking that something real was happening at around a mass of 125 GeV. New data would have allowed understanding fully the origin of the excess.

Since then, researchers launched a frantic activity in preparation of the new data taking. With LHC providing collisions at 8 TeV, all studies performed at 7 TeV had to be carefully re-done. In addition, in the effort of raising the instantaneous luminosity, LHC operators increased significantly the number of protons per bunch. As a consequence, the average number of interactions per crossing roughly doubled with respect to 2011 conditions, forcing analysts to review and sharpen further their analysis tools. Lastly, to avoid any kind of bias in looking at the new data, the collaborations decided to perform a so-called "blind analysis", meaning that nobody was allowed to look at the signal region before a certain date that was fixed to be mid-June. By then, after only 11 weeks of running in 2012, the accelerator had delivered an amount of data equivalent to the full 2011 data set. As soon as the "signal box" with new data was opened, the signals from 2012 data were appearing again, exactly in the same region, around 125 GeV, that had created so much excitement at the end of 2011. Now even the most prudent scientists within the collaborations started believing that they were witnessing the discovery of a new particle.

A second special seminar was called at CERN, on July 4th, 2012, the opening day of the ICHEP conference held this year in Melbourne (Australia). This time, by combining the 2011 and 2012 data, both collaborations presented striking peaks with statistical significance at or above 5.0 σ, the golden standard for any major finding in particle physics. It was definitely time to announce the long-awaited discovery of a Higgs-like boson with a mass near 125 GeV [9,10]. Although both collaborations reported excess in the $H \rightarrow WW$ channel, the evidence was strongest in the final states with the best mass resolution, $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4\,l$. For these channels we can clearly distinguish narrow bumps showing up in the invariant mass distributions in the vicinity of 125 GeV [Fig. 3, 4]. A fit to these signals allows measuring the mass of the new particle. The result is 125.3±0.4(stat.)±0.5(syst.) GeV for CMS, fully compatible with the ATLAS result 126.0±0.4(stat.)

▸ **FIG. 1:** Francois Englert (left) and Peter Higgs (right) at the CERN discovery seminar, July 4th, 2012.

[2] LHC operated at 3.5 TeV per beam (7 TeV collision energy) in 2010 and 2011 and at 4 TeV (8 TeV collision energy) in 2012.



±0.4(syst.) GeV. The strong signals detected in the decay of the new particle to two photons indicate that the new particle is a boson with spin different from one.

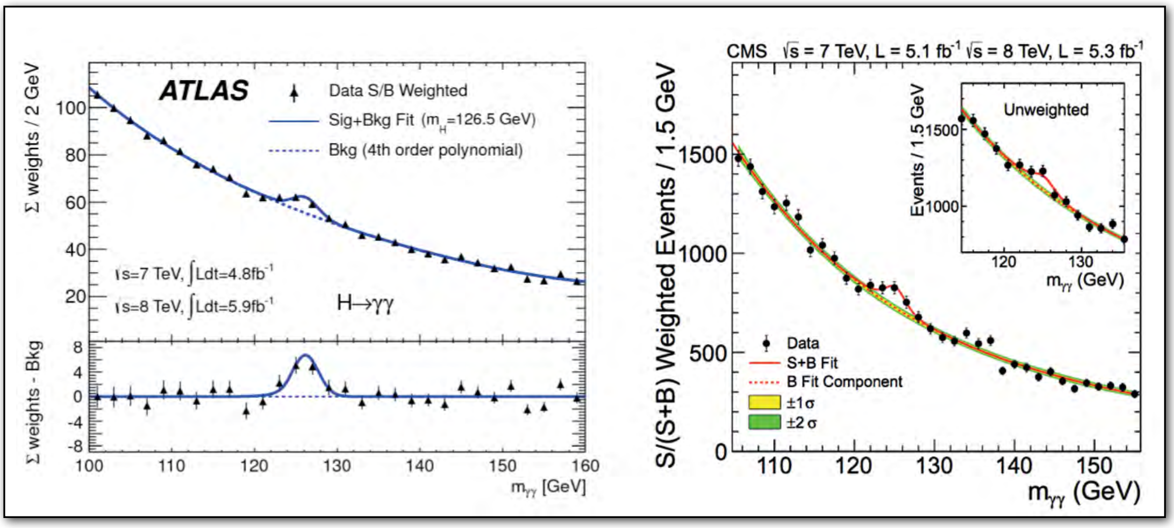
Implications of a New Boson with a Mass of 125 GeV

Meanwhile we celebrate a historical achievement; the work is definitely not over. Many questions are still on the table. First of all is the new particle really "the" SM Higgs boson? Are the strengths of its interactions with all other particles and with itself precisely the ones predicted by the SM? Is it alone or accompanied? Is it "elementary" or "composite"?

All these questions are still absolutely open. Measuring the quantum number of the new particle will be among the first priorities. There are good prospects to soon measure spin and parity of the new state of matter. Preliminary results show that this will be possible by carefully studying the angular distribution of the decay products in the two high-resolution channels, $H\rightarrow\gamma\gamma$ and $H\rightarrow ZZ\rightarrow 4\,l$. The two decay modes are quite sensitive and clean, but statistics is absolutely needed. The recent decision to extend the current pp run of LHC up to the middle of December is therefore excellent news. There are therefore realistic hopes to reach integrated luminosities for 2012 in the range of 25-30 fb^{-1}.

The most challenging task will be to measure the couplings well. Being so sensitive to any new particle, the freshly discovered Higgs-like boson could act as a portal for new physics beyond the SM. Both ATLAS and CMS have produced results on the signal strength, expressed as a ratio with respect to the SM expectations, σ/σ_{SM}, in different decay modes. ATLAS and CMS results on this quantity (1.4±0.3 and 0.87±0.23 respectively) are fully compatible with the SM prediction (Fig. 5). Still they are very preliminary results and for some modes, like decays

▲ **FIG. 2:** The Large Hadron Collider and its two general-purpose detectors: ATLAS and CMS.



◀ **FIG. 3:** Di-photon invariant mass distributions for ATLAS and CMS. A narrow bump is clearly showing-up around 125 GeV.

to t-leptons or b-quarks, the current data are not yet able to distinguish a SM signal from background. So far, we can only conclude that the Yukawa coupling of the new particle to fermions has not been firmly established by the LHC experiments. By looking instead to the couplings to bosons, the ratio of the couplings to W and Z, which is protected by the custodial symmetry, seems to be consistent with expectations in both experiments. The only possible hint of an anomaly comes from some intriguing difference, with respect to the SM prediction, reported in $H \rightarrow \gamma\gamma$ by both experiments. ATLAS measured 1.8±0.5, and CMS 1.6±0.4. Still too early to draw any conclusion, but it will be worth to closely follow this issue. The Higgs boson cannot couple directly to photons, therefore the coupling proceeds through loops of virtual particles involving heavy bosons or fermions. For the known objects in the SM, loops of W and of top quarks dominate the mechanism. New, heavy particles, like the ones predicted in Supersymmetry (SUSY) models, or some of the massive objects predicted by Extra-Dimensions models could enter into the game and modify the rates. If experimental data will definitely show an anomaly here this could be the first un-ambiguous evidence of physics beyond the SM. From careful measurements we could even indirectly infer its energy scale. Only additional data will tell us if these preliminary hints will fade away or if there is something happening there.

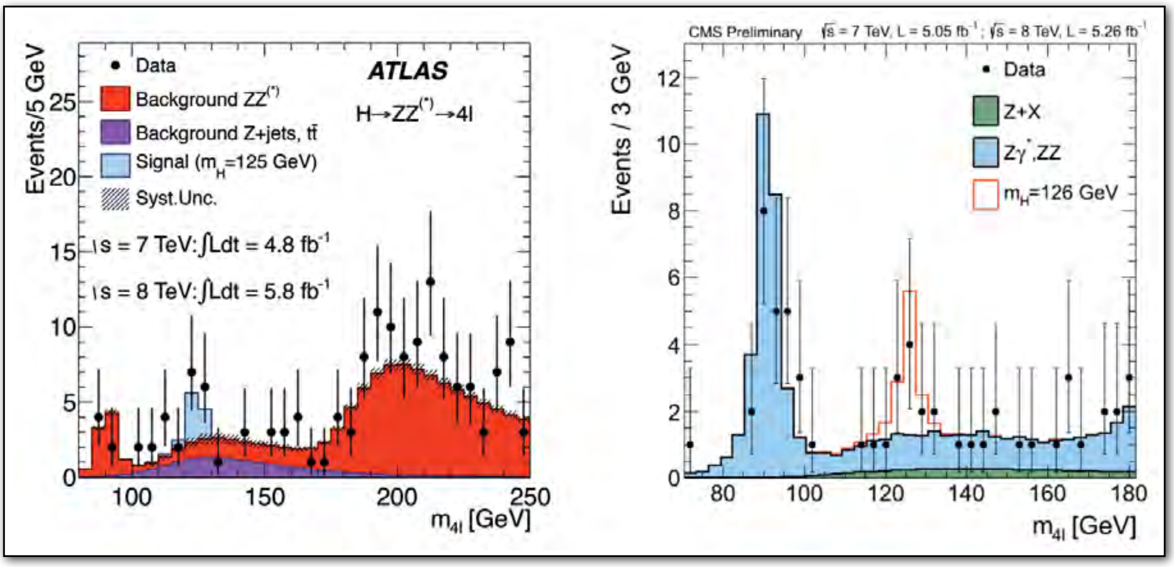
A Higgs-like particle of mass 125 GeV puts strong constrains on many SUSY models. SUSY could be consistent with a Higgs-like boson but it would prefer it to be lighter. There is room still to accommodate this relatively heavy object but a precision measurement of the couplings will add important additional constrains. The combination of direct and indirect searches for SUSY, and the implications for SUSY coming from the measurement of mass and couplings of the new boson, will relatively soon lead either to a discovery of super-symmetry or to a drastic revision of some of its paradigms.

The Problematic Triumph of the Standard Model

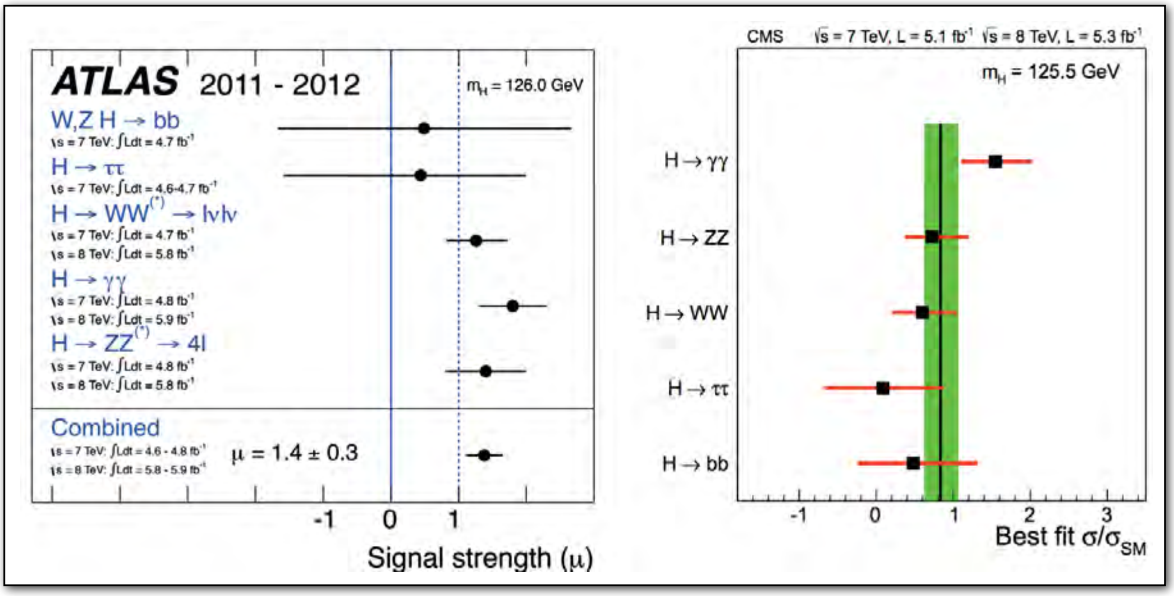
If it will come out that no anomaly will survive the scrutiny of additional data, we will be forced to conclude that the newly discovered particle is precisely the SM Higgs. At that moment we could say that we have understood what happened at about 10^{-11}s after the big bang. When the average temperature of the universe was about 100 GeV, the electroweak symmetry-breaking mechanism entered suddenly in action. The weak force was separated from the electromagnetic one, and leptons and quarks acquired a mass giving shape to the evolution of the universe that lastly produced everything we know including us. Still, in the exact moment in which we celebrate another triumph of the Standard Model, we know that, even including the Higgs, the SM remains an incomplete theory. We know it does not account for the many phenomena that play big roles in the evolution of our universe. What is the mechanism responsible for the inflation? What is the origin of dark matter and dark energy? Why is gravity so weak? What is the source of the large asymmetry between matter and anti-matter? And so on.

We do not know at which energy scale we shall be able to find answers to some of these fundamental questions. Today we have in hand another sensitive tool to explore some of them. The newly discovered particle must be studied in detail. We are doing it already with LHC running at 7(8) TeV. A much better job will be possible in 2014 as soon as the machine will upgrade its energy to 13.5 or 14 TeV. But we are also aware that a hadron collider is not the best environment to perform precision studies. Colliding leptons is by far the right choice. The European High Energy Physics community is facing important discussions already. While LHC is producing new data and CERN experiments continue to yield new information, it is a very appropriate moment to address a few compelling questions.

Would it be technically possible to build a new lepton collider to study in detail the new boson and measure precisely all its properties? And if the answer is yes, what would be



▸ **FIG. 4:** Four-lepton invariant mass distributions for ATLAS and CMS. Higgs candidate events clusters in the narrow bump around 125 GeV. The large peak around 90 GeV seen in CMS is due to a rare decay of the Z particle recorded for calibration purposes.



◂ **FIG. 5:** Preliminary measurements of m, the ratio of the signals strengths in different decay modes with respect to the SM expectation for ATLAS and CMS.

the best investment: a challenging new Linear Collider producing collisions at 250 or 400 GeV and/or a less ambitious LEPIII machine running beyond the Z-H threshold? And if we'll be so lucky, sometime in the future, to collect evidence for additional physics in the 10 TeV region, would it be realistic to consider doubling the energy of LHC? As it happened already several times in the past, with a new discovery an era comes to an end, and we already might have entered a new era whose contours, to be really well defined, will need the active contribution of the whole community.

Conclusion

By analyzing the 2011 and 2012 data, the ATLAS and CMS experiments have discovered a new boson around a mass of 125 GeV. The result is consistent, within uncertainties, with expectations for a standard model Higgs boson. The collection of further data will enable a more rigorous test of this conclusion and an investigation of whether the properties of the new particle imply physics beyond the standard model. ■

Acknowledgements

I would like to thank the LHC team for achieving such an impressive performance in the operation of this machine and the thousands of "unknown heroes" that worked for years within ATLAS and CMS to make this discovery possible.

About the Author

Guido Tonelli is a full professor in general physics at the University of Pisa (Italy) and a researcher at the Italian Institute for Nuclear Physics (INFN). He has pursued high-energy physics research in several CERN and Fermilab experiments. The last two decades of his career have been devoted to the search for the Higgs boson and for signatures of new physics beyond the Standard Model. He has been working on the CMS experiment at CERN since 1993, having served as its spokesperson in 2010 and 2011. In that capacity, in December 2011, he delivered one of the two CERN presentations showing the initial evidence for a Higgs boson at 125 GeV. He is author of about 450 scientific publications.

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The adventure of quasicrystals: a sucessful multidisciplinary effort

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The 2011 Nobel Prize for chemistry was awarded to Daniel Shechtman from the Technion Haifa (Israel) for his discovery of quasicrystals in 1982. At the time, he was visiting the National Bureau of Standards (now NIST, Gaithersburg, Maryland, USA). While performing an electron microscopy study of rapidly solidified aluminium alloys, he observed precipitates with beautifully resolved sharp diffraction spots with 5-fold symmetry as shown on fig 1 (a). His surprise was such that he initially refused to publish this unbelievable result.

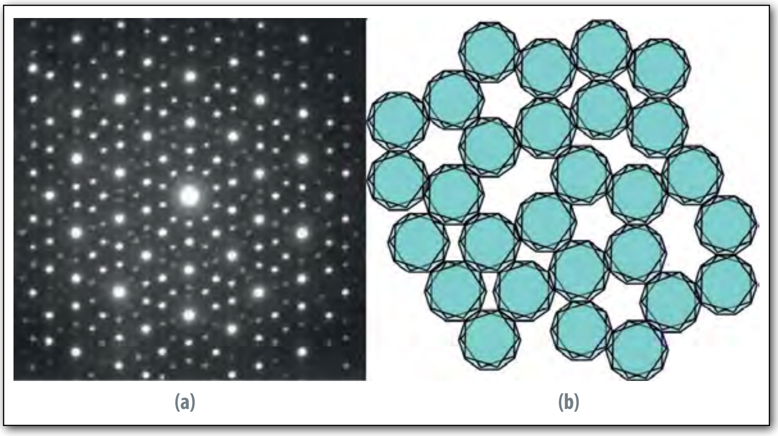
▲ Tile decoration, Alhambra Palace, Grenade, Spain. It is not a quasicrystal structure but makes a pleasant illustration related to it. © iStockPhoto

He first wanted to find an explanation for this paradoxical result *of an object diffracting like a perfect crystal but with overall 5-fold symmetry that forbids it to be periodic*. As Dan said: "there is no such animal". It was only in late spring1984 that Ilan Blech, one of his colleague at Technion, devised a very clever model of random stacking of parallel regular icosahedra linked by the edges and that showed strong diffraction peaks at the wavevector positions observed by Shechtman.

At about the same time, Shechtman consulted John Cahn, Senior scientist at NIST (NBS), who suggested him to focus on the experimental fact of the paradox of Bragg diffraction showing a non-crystallographic symmetry in a solid. Shechtman invited Cahn to write such common paper that eventually became the PRL paper with the help of Gratias who revealed the work of H. Bohr and A. Besicovic on almost-periodicity, thus confirming the possible existence of Bragg diffraction for non-periodic objects. This led to the two papers [1] that announced the discovery of quasicrystals.

Prolegomena of quasicrystals

As very often in science, the concepts that were at the basis of quasicrystals were already known for a long time! In 1972, Yves Meyer [2] published a book on Harmonic Analysis and Number Theory in which he invented the so-called harmonious ensembles that are non-periodic sets of points that diffract on enumerable sets of Bragg peaks. These harmonious ensembles are now recognized as the first quasicrystals. In 1977 Pieter Marten de Wolff, followed by Aloysio Janner and Ted Janssen [3], invented the superspace description for describing incommensurate phases. A few years before, in 1974, Roger Penrose built a non-periodic tiling made of two kinds of tiles with an overall 5-fold symmetry [4]. In 1981, Alan L. Mackay choose the Penrose tilings as prototypes of possible atomic distributions with 5-fold symmetries in a magnificent pioneering paper [5] *De Nive Quiquangula: on the pentagonal snowflake* where he concluded: *"it gives an example of a pattern of the type which might well be encountered but which might go unrecognized if unexpected"*. The link between the Penrose tiling and the superspace description started with the 1981 paper *Algebraic theory of Penrose's non-periodic tilings of the plane* by Nicolaas Govert de Bruijn [6] who discovered the hidden properties of this tiling in considering internal variables that would later be shown as the basis of the cut method. Soon after, in 1984, Peter Kramer and Roberto Neri [7] found new periodic and *non-periodic* space fillings by projection from higher dimension spaces. Finally, a few weeks after Shechtman's publication, Dov Levine and Paul Steinhardt [8] proposed the first explicit ideal structural model that they designated as *quasicrystals*, an abbreviation for quasiperiodic crystals.



▲ **FIG. 1.** (a) Electron Diffraction pattern of dendritic precipitates in rapidly quenched Al6Mn alloy showing a 5-fold symmetry forbidden by crystallography. (b) Ilan Blech's first multipolyhedral model of randomly distributed Al12Mn parallel icosahedra connected by the edges.

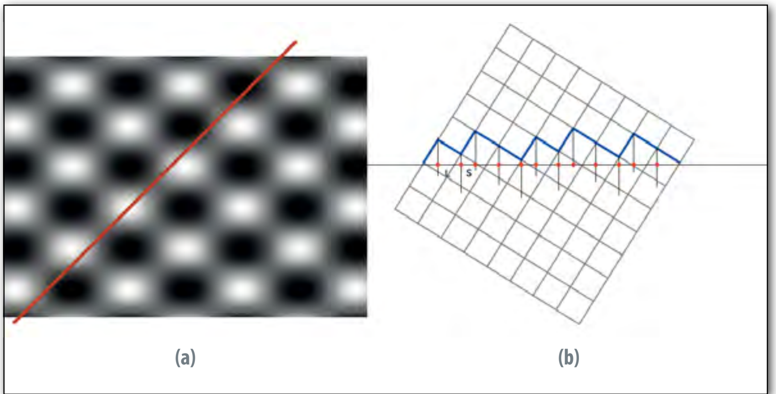
The basics of quasiperiodicity

The common feature between these theoretical works and Shechtman's experiments is the fact that symmetries are hidden in a higher dimension space. This is best understood in the reciprocal space: the diffraction patterns like Fig. 1(a) have the remarkable property that *all the diffraction spots q can be indexed using 6 integers n_i, $q = \sum n_i e_i$, with unit vectors e_i defined by the six 5-fold axes of the icosahedron*. So the diffraction spots can all be viewed as the *projections q* in the physical 3-dim space, of 6-dim vectors Q of a *regular periodic* (reciprocal) lattice in a 6-dim Euclidian space. In direct space, this corresponds to an *irrationally oriented cut* of a periodic object in a 6-dim space. This is the definition of quasiperiodicity: a quasiperiodic pattern in a D-dim space is the result of a D-dim irrationally oriented *cut* of an N-dim periodic pattern with $N>D$ as illustrated on Fig. 3(a) and (b).

Quasicrystals immediately accepted

In January 1985, Louis Michel and Marjorie Senechal organised a workshop of mathematical crystallography at the *Institut des Hautes Etudes Scientifiques* (IHES- Bures/Yvette)

◂ **FIG. 2.** (a) from right to left D. Shechtman, I. Blech, D. Gratias and J.W. Cahn (CNRSPhotothèque-Pierre Grumberg). (b) Example of a typical Penrose tiling showing local 5-fold symmetry.



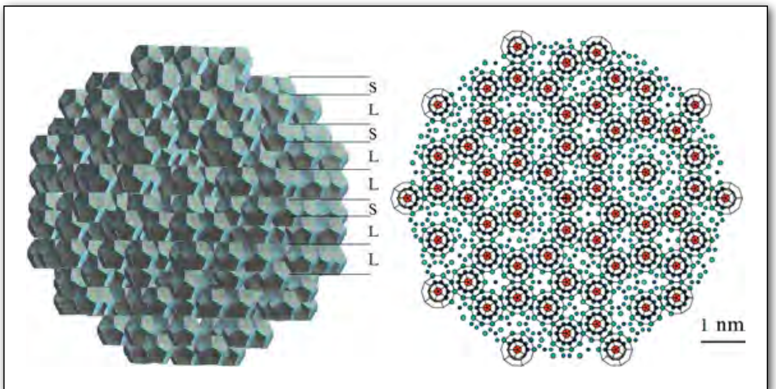
▲FIG. 3. (a) The 1-dim quasiperiodic function $f(x)=\cos x+\cos\sqrt{2}x$ is the (x=y) cut of the 2-dim periodic function $F(x,y)=\cos x+\cos\sqrt{2}y$. (b) Cutting a square lattice by a straight line of irrationnal slope $1/\tau$ (where $\tau=(1+\sqrt{5})/2$ is the golden mean) and projecting the upperleft vertices of the intersected squares generates the (quasiperiodic) Fibonacci sequence of long (L) and short (S) segments.

near Paris and invited Shechtman, Cahn and Gratias to present their results. Michel Duneau, André Katz and Aloysio Janner were in the audience and immediately after Gratias's talk, Michel Duneau and André Katz [9] explained on the blackboard the technique of the cut method (see Fig. 3) whereas Aloysoi Janner made the connection with the superspace description: in that extraordinary afternoon session, the very bases of this *new quasicrystallography* were posed. The cut method has been independently confirmed by the Russian group Pavel Kalugin, Alexei Kitaev and Leonid Levitov [9] and by the American Veit Elser [9].

Quasicrystals received a unanimous enthousiastic interest from the mathematics and solid-state physics communities. The research developed very quickly in Europe: in France, with a joined research programme (PICS) with the NBS (Gaithersburg, Maryland, USA), the first International Workshop on Quasicrystals in Les Houches (March 1986), the creation of the *Groupe de Recherche* CNRS *Quasicristaux* untill the 90's, and then, starting 1997, in Germany with the DFG *Schwerpunkt Quasikristalle*. Together, more than a hundred European laboratories have been involved in those programmes with quite comfortable financial support. Parts of these efforts are still very active today in a European Network of Excellence on Complex Metallic Alloys (CMA) that gathers 21 European Countries.

Although no scientific revolution has ever been easier than quasicrystals in Europe, the situation has been slightly different in the US. In fact, in a letter to Nature [10] in October 1985, the famous double Nobel Prize chemist and crystallographer Linus Pauling rebels against these quasicrystals that he thinks were simple multi-twinned ordinary crystals: *"crystallographers can now cease to worry that the validity of one of the accepted bases of their science has been questioned"*. Strong refutations have immediately been published [10] in the January 1986 issue of *Nature "Pauling's model not universally accepted"* signed by several groups, but most of the US crystallographers stayed outside the field during many years. This has been the opportunity for European and Asiatic scientists to take some advance in sample preparation techniques and crystallography, whereas the US physicists developed mostly the entropy aspects with the random tilings models.

▼FIG. 4. Typical example of quasiperiodic i-AlCuFe structure made of an ordered imbrication at long distance of atomic clusters (shown here are the so-called Bergman clusters made of a central atom, an icosahedron and an external icosidodecahedron). A cut of the structure perpendicular to a 5-fold direction shows that the clusters are connected by edges of the external icosidodecahedra like in the Blech random tiling model. As on the left, the clusters stack along the 5-fold axes according to Fibbonacci sequences. The chemical species distribute on the various orbits of these clusters.



Atomic structures of quasicrystals

New quasicrystalline structures are rapidly discovered since 1985 : the decagonal phase is identified by L. Bendersky [11] at NIST, and then, a series of icosahedral metastable phases are found mostly in ternary aluminium-based alloys. In July 1986, P. Sainfort and B. Dubost, from the research center Cegedur-Péchiney near Grenoble, discover the first millimeter size stable quasicrystal [11] obtained by slow solidification in an Al-Li-Cu(Mg) alloy. Soon after, A.P. Tsai [11] finds an impressively large number of new stables icosahedral and decagonal phases.

This started the process of making quantitative X-ray and neutron single-grain diffraction studies. In November 1990 M. Cornier-Quiquandon *et al.* made a first structure determination of the $Al_{62}Cu_{25.5}Fe_{12.5}$ single-grain icosahedral phase by neutron diffraction at LLB (CEA-Saclay, France). They used the cut and devised atomic surfaces inspired by previous work from P. Guyot et M. Audier, who proposed structural units (Mackay clusters) for quasicrystals from a study of the unit cells of the crystalline phases α-(AlFeSi) and α-(AlMnSi) (see Fig. 4). Independently, in 1992, M. Boudard *et al.* obtained very similar results on the alloy $Al_{70.3}Pd_{21.4}Mn_{8.3}$ using X-ray diffraction at ESRF (Grenoble). In both cases, the result was surprisingly simple: the atomic structure, like the one shown on Fig. 4, can be described by three atomic surfaces located a the high-symmetry special points of the 6-dim lattice.

The cut method is now successfully used on many other quasicrystalline icosahedral and decagonal phases including the most recently discovered phases in the (Zn,Mg,Ho), (Zn,Sc,Mn) and (Cd, Yb) systems.

Physical properties

Quasicrystals have very early on been recognized as Hume-Rothery phases with a pseudo gap near the Fermi level. A. P. Tsai — discoverer of almost all recent quasicrystals — has always been guided by the phenomenological criterion of the number of electrons per atom (*e/a*) and the ratio of the covalent atomic radii of the alloy components to find new stable quasicrystals. Concerning transport properties, quasicrystals have very unique behaviour: their electrical resistivities at low temperature are several orders of magnitude larger than those of their components, similar to those of doped semiconductors. Moreover, contrary to usual metals, the resistivity increases with the quality of the quasicrystal and varies with temperature as an inverse Matthiesen rule! This phenomenon could be connected to a strong localisation of the electrons in the atomic clusters (see Fig. 4) and the many *umklapp* processes that could prevent electrons to jump from one cluster to the other. Similarly, quasicrystals have low thermal conductivity at low temperature. They could be used as coating in liquefied-gas containers. Also lattice dynamics of quasicrystals have very specific properties due to the existence of many neighbouring atomic sites that are mutually exclusive, thus generating phasons (analogy to incommensurate phases) that are discontinuous atomic jumps at finite distances, as first observed by quasi-elastic neutron scattering. It is now suggested that these atomic hopping modes are strongly dissipative, but the origin of this dissipation is still poorly understood. The mechanical properties of quasicrystals are very similar to those of complex intermetallics with large unit cells (Laves and/or Frank-Kasper phases). They are highly brittle at low temperature and ductile only close to their melting points. The dislocations in quasicrystals are defined in the N-dim space in the same manner as for ordinary crystals, but their motions are restricted to high temperature where they move essentially by climb.

As a conclusion…

Quasiperiodicity does not exhaust, by far, all possible ordered solutions: many other mathematical deterministic algorithms exist that give rise to perfectly ordered distributions of points that are neither periodic nor quasiperiodic. It is not yet known which of these distributions could appear in Nature but, because of quasicrystals, it is clear that solid-state physicists are much better prepared to face these new possibilities today than in the 1980s. What is less clear is the present capability of the Europeans research agencies to quickly react and federate a multidisciplinary research in front of a hypothetical new "quasicrystal" discovery. ■

About the Author

Born in 1947, **Denis Gratias** received his diploma of the Ecole Nationale de Chimie de Paris in 1970 and made his Doctorate on the Crystallography of homogeneous interfaces in crystals in professor Michel Fayard's laboratory in Paris. He then worked with professor Louis Michel at the Institute of High Scientific Studies (IHES-Bure/Yvette) and Professor Didier de Fontaine at the University of California Berkeley in statistical physics. Professor J. W. Cahn invited him to a longterm seminar at University California Santa-Barbara where he learned in summer 1984 about the astonishing results of D. Shechtman. He joined the group of Cahn at NIST and participated to the first paper announcing the discovery of quasicrystals. He then specialized in quasicrystal structure determination using N-dim crystallography and he studies now the defects observed in quasicrystals like dislocations and the metadislocations in their approximants.

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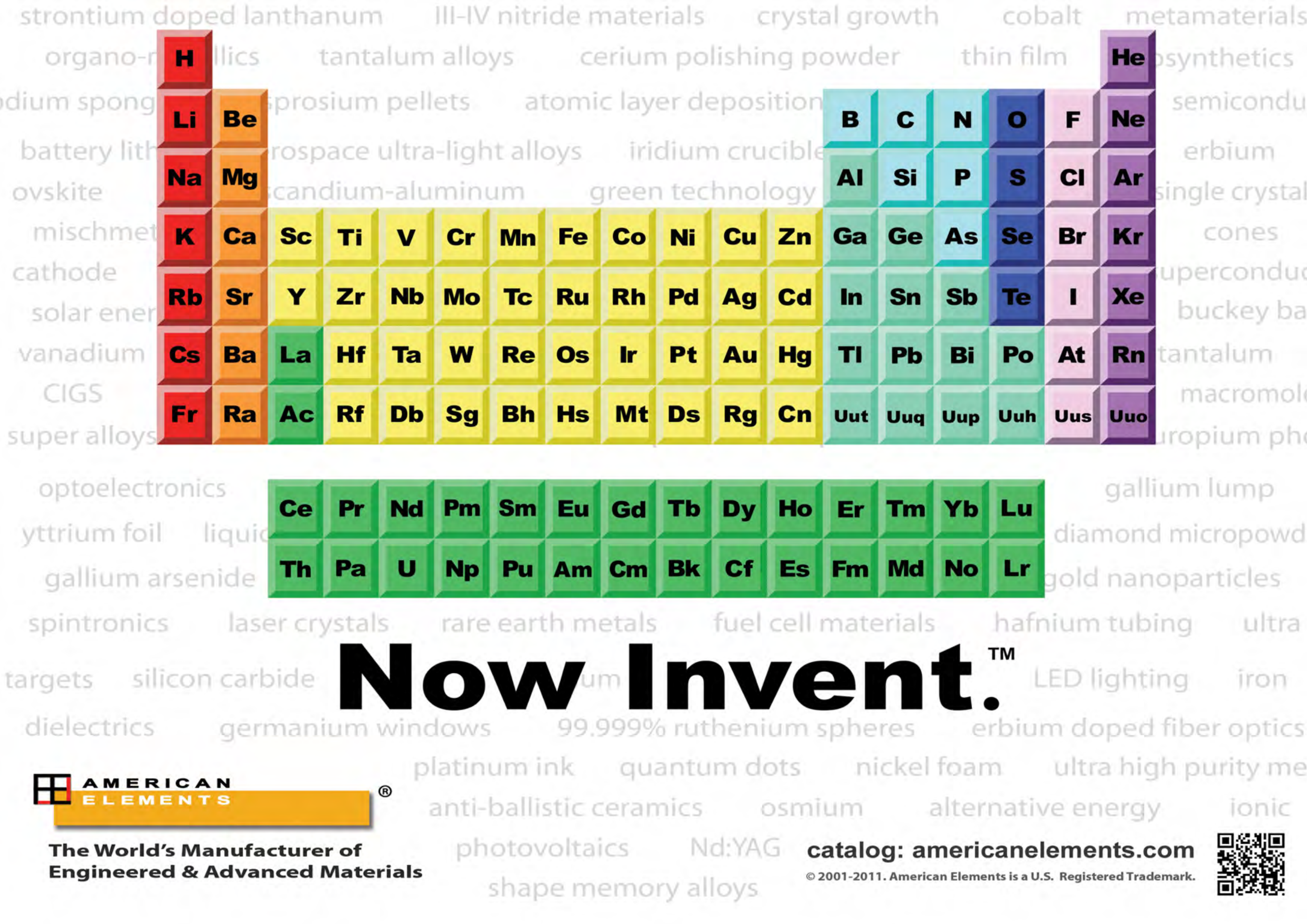
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