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Walking droplets
Frontiers of QCD at hadron colliders
Weak neutral currents discovery
Cosmic rays and global warming
Bubbles and balloons

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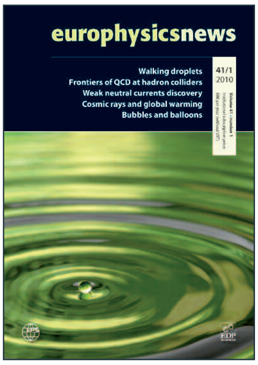

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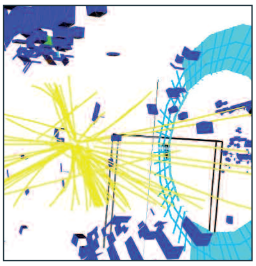
Cover picture: Water drop on surface of water with green reflection from background vegetation. © iStockPhoto
See p.14 "Walking droplets, a form of wave-particle duality at macroscopic scale?"



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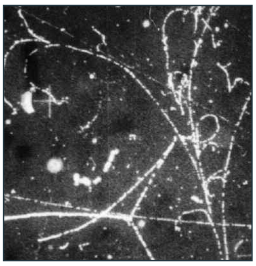
Frontiers of QCD at hadron colliders



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Weak neutral currents discovery

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Physics in daily life: Bubbles and balloons

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FEATURES

Do we need a European Doctorate?

A University is essentially the unique creation of the European Middle Ages as a higher education institution. At those times a fairly homogeneous culture founded on the Christian religion and the Latin language resulted in a rich exchange of ideas and people from different countries, although each University was proud of its distinctive tradition.

The diversity among European Universities that concerns us here refers to the variable quality of research and advanced studies. In a competitive and commercial world such as ours, University classifications exist that stress such differences which may become a critical issue in obtaining funding or in recruiting good students. The current situation of European Universities regarding scientific disciplines, such as physics, is easy to summarize. On the one side there are Institutions with a long tradition, such as, Cambridge, Oxford, Scuola Normale Superiore of Pisa and the Swiss Polytechnic Schools, which offer excellent tuition and whose PhD degrees are highly rated. These are Universities with selective entrance criteria, and consequently able potentially to enroll more talented students. In practice, however, the situation is much more dynamic. In fact there are many other gifted students in other Universities that can boast outstanding research groups together with lower quality ones. But in a competitive environment these Universities may be unable to gain a reputation for their advanced studies such as the top European, American and, by now, the Far East Universities.

This raises the question: do we need a European Doctorate in physics? Awarding a single Ph.D. independent of the University involved could be a positive response, but not to achieve anonymous uniformity. The variety of traditions and cultures, reflected in different approaches to research in and teaching of physics, is a unique intellectual capital of Europe to be preserved, emphasized and strengthened. But as a single grouping, all European Universities, both the small ones, although great their cultural past may have been, and the large ones, with hundreds of students in physics and large and active research groups, face the same problem: how to ensure the visibility of their advanced studies and the recognition of the quality of their best Ph.D. students, which are often blurred among a plethora of excessively specialized degrees and of Universities.

These are the main reasons that we propose the introduction of a European Ph.D. in physics. It should be awarded to the best students after a course of studies and a research project whose level and standards are certified by an international board of scientists. European networks of suitably selected Universities could offer a single European Ph.D. in a range of topics in physics, such as condensed matter physics, particle physics, astrophysics, etc. They would have access to European funding, could organize lectures and advanced schools on specialized timely subjects given by top experts to a solid group of highly motivated and keen students, and could avoid any cumbersome bureaucracy of too large Institutions. A network would also allow students quickly to make planning stays at partner Universities to access proficiently a new experimental technique or a numerical code, not available at their home University. ■

Gian Paolo Brivio,
Dipartimento di Scienza dei Materiali, Università di Milano-Bicocca (Italy)
Coordinator of the European network for the doctorate
in 'Physics and Chemistry of Advanced Materials' (PCAM)

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2009 awards of

The EPS Plasma Physics division

At their annual conference, held from June 29th – July 3rd in Sofia, Bulgaria, the EPS Plasma Physics Division rewarded excellent achievements in scientific or technological research.

Hannes Alfvén Prize

The 2009 divisional Hannes Alfvén Prize was awarded to Professor Doctor **Jürgen Meyer-ter-Vehn**, the Head of Laser Plasma Theory Group, at the Max-Planck-Institut für Quantenoptics, Garching and an Honorary Professor at Munich Technical University (Germany), *"for his outstanding theoretical work in the fields of inertial confinement fusion, laser-matter interaction, and, specifically, relativistic laser-plasma interaction and laser wake field electron acceleration."*

▲ Jürgen Meyer-ter-Vehn

J. Meyer-ter-Vehn is well known to the plasma physics and nuclear fusion community as an outstanding scientist in the fields of inertial confinement and laser-matter interaction. His career in this domain started in the early 80s when he joined the laser fusion group at the MPQ. In a few years, he contributed to the development of the approach to inertial confinement fusion by using converging shocks and x-ray thermal radiation. At the MPQ in Garching, just outside Munich, and at the Institute of Laser Engineering in Osaka, he has developed, with R. Sigel and others, a rather complete theory of the x-ray generation, confinement and ablative drive that was confirmed later by experiments. The drive creates the conditions for efficient transformation of the laser energy in thermal radiation with temperatures exceeding 200 eV, and shows how it can be used for the compression of fusion pellets. It became apparent a few years later that this approach, now known as indirect drive fusion, was the one to be used for the upcoming initial demonstration of ICF breakeven at the MJ-scale laser installations in the USA and in France. The ICF community acknowledged the significant contribution of J. Meyer-ter-Vehn to this field in 1997 with the Edward-Teller Award, the most prestigious recognition in the inertial confinement fusion domain.

This major advance was not a conclusion of his scientific achievements, but just another stepping stone in his passionate quest for an efficient and reliable source of inertial fusion energy. A phenomenal progress in high power laser technology at the end of the 1980s and the fast ignition approach propounded in the 1990s by American scientists provided a way for more flexible and efficient target designs. These developments opened up a new area of relativistic laser-plasma interaction so rich in outstanding results. J. Meyer-ter-Vehn has mainly contributed to laser-assisted charge particle acceleration and their application for the ignition of fusion targets. In particular, he proposed with A. Pukhov a new method of laser wake field acceleration of electrons in the blow-off regime that has been confirmed by experiments in 2004. He is continuing this work by studying new schemes of electron and ion acceleration and their applications in quantum electrodynamics and nuclear physics, bringing together these rather disparate communities.

J. Meyer-ter-Vehn has taught young scientists from many countries and, in 2004, he wrote a book with S. Atzeni on the Physics of Inertial Fusion. This brought about international propagation of the values of science in general, the theoretical plasma physics and fusion research.

This laudation only addresses the principal areas in which this exceptionally gifted scientist has made important contributions to the progress in the plasma and fusion research. It is especially appropriate and timely, in a year when the National Ignition Facility is making its first shots. It is intended to demonstrate break-even by using the approach that contains the crucial contributions made by Jürgen Meyer-ter-Vehn.

The Plasma Physics Innovation Prize 2009

The 2009 Plasma Physics Innovation Prize of the EPS is awarded to Professor Doctor **Emmanuel Marode**, Directeur de Recherche, Laboratoire de Physique des Gaz et des Plasmas, Ecole Supérieure d'Electricité, Gif sur Yvette (France) *"for breakthrough*

▲ Left to right: Cedric Thaury, Ian Chapman, Tilmann Lunt

developments and applications of basic plasma physics tools to address environmental concerns."

E. Marode has made pioneering and innovative contributions to low temperature plasmas and their industrial and societal applications throughout his forty years tenure at the Ecole Supérieure d'Electricité in France.

One high-impact area of his research that deserves to be singled out for its environmental implications is that of pollutant and combustion control using the chemical activation of cold electrical discharges. It showed that energy can be channelled in different ways in order to meet given objectives, according to how it is distributed in the various discharge sequences. It also showed that both the experiments and the modelling confirm the idea that electrical discharge causes a highly localised injection of reactive substances, which spread, and ultimately react, with the entire gaseous medium. Rather than being transformed into pure heat loss, this energy can be then be utilised, for example, to selectively destroy undesirable molecules, or to provide a non-thermal trigger for motor combustion.

From the early days of his career to the present day, E. Marode has been a relentless advocate of computer simulations to aid the understanding of the very complex phenomena that characterise low temperature plasmas.

As a final example of the importance that E. Marode attaches to the useful applications of low temperature plasmas, one must cite at least one of his patents for the plasma reactor invented by him in conjunction with Micheline Palierne, Salem Achat and Yves Teisseyre.

▼ Emmanuel Marode

The PhD Research Award 2009

A committee comprising **Jack W. Connor**, **Jean-Claude Gauthier** and **Hans J. Hartfuss** has judged the 2009 PhD Research Award of the Plasma Physics Division. They examined all the candidatures in a process managed by Dimitri Batani. The EPS PhD prize is a key element of the EPS PPD activities to recognise the exceptional quality of work carried out by young physicists. The jury nominated 3 award winners from an impressively high quality set of candidates. The 2009 citations, in alphabetical order, are:

Cedric Thaury from CEA-Saclay, France, for the first principles study of effects in nonlinear laser–plasma interaction including high-order harmonic generation of intense laser light by reflection at a plasma mirror. Identification of a novel mechanism at lower laser power ('Coherent Wake Emission'), as well as a clear characterisation of its properties and detailed comparison with the known 'Relativistic Oscillating Mirror' process occurring at higher power.

Ian Chapman from UKAEA Fusion Association, UK, for the sophisticated theoretical modelling, integrating theoretical ideas on linear stability into, and then developing, state-of-the-art codes for describing saw tooth behaviour. This modelling is validated by comparison with the detailed behaviour of saw tooth periods in a range of European tokamaks. Furthermore, the work has improved the understanding of the saw tooth control techniques that can be employed in ITER.

Tilmann Lunt from Max Planck Institute of Plasma Physics, Germany, for impressive diagnostic development and its application to a fundamental aspect of the plasma sheath, the Bohm criterion. This work is significant with regard to experimentally validating the interpretation of probe data, and the Bohm criterion forms the basis for aspects of divertor modelling, *e.g.* for ITER. ■

▮▮▮ **Carlos Hidalgo**, Chairman of the EPS Plasma Physics Division

Report on MPTL-14*

***14th International Conference on Multimedia in Physics Teaching and Learning**

The 14th International Conference on Multimedia in Physics Teaching and Learning (MPTL) was organized at the University of Udine (Italy) from Sept. 23 to 25, 2009 by Prof. Marisa Michelini. It was attended by about 100 participants representing more than 30 countries.

This was the largest MPTL conference so far. 43 oral presentations were grouped in parallel sessions, in addition to 7 plenary talks. Moreover, hands-on workshops were offered on remote laboratories, interactive lecture demonstrations, 3D programming using VPython, Easy Java Simulations, and on the MOSEM2 project. Finally, more than 20 interactive posters and almost 40 regular posters attracted much interest. For the first time, a prize (donated by the European Physical Society) was awarded to the best students´ poster presentation.

The workshop was very successful, in part thanks to the collaboration of many organizations, including the European Scientific Education Association, GIREP, the International Commission on Physics Education, the Latin American Physics Education Network, MERLOT, CoLoS, MOSEM, STEPS2, the Italian Association for Physics Teaching, and the Italian Physical Society.

Compared with previous meetings, one could notice a marked increase in contributions from high schools and especially from primary education, as well as more contributions from physics education research.

The plenary talks covered a wide range of topics :

Wendy Adams (University of Colorado, Boulder, USA) talked about research that showed actual improvements in student engagement and learning when they use PhET interactive simulations.

Elena Sassi (University of Naples, Italy) and **Sonja Feiner-Valkier** (Eindhoven University of Technology) discussed the use of multimedia in the more general context of student-centred and project-based learning. They also presented the activities of the STEPS-TWO project on this topic.

Bruce Mason (University of Oklahoma, USA) and **Robert Sporken** (University of Namur, Belgium) reported on the evaluation of MM software on waves and optics, performed in cooperation by an American (MERLOT) and a European (MPTL) group. This is the continuation of a program in which one field of physics is investigated each year: it starts with a worldwide search for MM programs, which are then surveyed and evaluated, resulting in recommendations for excellent products.

Michael Ross (University of Colorado, Boulder, USA) showed how a simple data collection and analysis tool can be taken into primary school to help elementary students develop scientific and communication skills;

Wolfgang Christian (Davidson College, North Carolina, USA) and **Bruce Mason** (University of Oklahoma, USA) presented pedagogical and technical features of curricular material developed under the Open Source Physics project and on the current effort to distribute it via a partnership with the comPADRE National Science Digital Library.

Finally, **Francisco Esquembre** (University of Murcia, Spain) discussed recent developments in Easy Java Simulations, including the new 3D drawing framework.

On the occasion of MPTL-14, participants were invited to the beautiful Udine Castle, where they were greeted by the Mayor of Udine and had the privilege of listening to an inspiring talk by Professor **Anthony French** on the work of Galileo.

The next MPTL workshop will be a joint organization with GIREP. It will be held in Reims, France, from **August 22 - 27, 2010.** ■

▼ **From left side of the table,Bruno Seravalli, Inspector representing the Regional Office of Italian Ministry of Education, Marisa Michelini, head of Physics Department and organizer of MPTL14, Leopold Mathelish, President of MPTL EU Group, Michele Morgante, Rectors' Delegate for Research in Udine University, Lorenzo Santi, head of Interdepartmental Centre for Research in Education**

▮▮▮ **L. Mathelitsch**, Univ. Graz, Austria and **R. Sporken**, Univ. Namur, Belgium

EPS Poster Prize at MPTL-14 to Stefano Vercellati

At the MPTL 14 workshop in Udine, a Europhysics Conference co-organized by the EPS Physics Education Division (PED), EPS made available a prize for the best poster prepared and presented by a PhD student. The prize consisted of a certificate and a money award of € 500.

The participants of the workshop could give their opinions; the final decision was made by a jury consisting of Elena Sassi (PED, Naples), Leopold Mathelitsch (co-chair of MPTL, Graz) and Urbaan Titulaer (PED, Linz, chair).
The prize was awarded to Stefano Vercellati of Udine University. In his poster, *A Discussion of Disciplinary Knots on Electromagnetism and Superconductivity on a Web Environment in the context of an EU Project (MOSEM) for Research-based In-service Teacher Training* he presented a course element developed for the master programme IDIFO2, "Innovation in Physics Teaching" directed at high school physics teachers. The course is offered in blended learning mode by a consortium of 15 Italian universities, led by Udine University.

▲ Stefano Vercellati, laureate of the EPS Poster Prize at MPTL

The course element makes use of *MOSEM* web material on electromagnetism and superconductivity. The participating teachers are presented with possible (wrong) student answers to problems posed in this material, asked to identify the "conceptual knots" behind the mistakes and to devise strategies to deal with them, involving, *e.g.*, cooperative learning methods and targeted experiments. An example concerning electromagnetic induction was shown in the poster.
Mr. Vercellati also presented a second poster, showing course material for science in elementary school. The material deals with kinematics: pupils are asked to "construct" simple trajectories, such as a circle, a parabolas or an Archimedic spiral, both by means of a prescribed sequence of forward and sideways steps on the classroom floor and by Flash animation on their computers. ■

Urbaan M. Titulaer, Johannes Kepler University, Linz, Austria

Condensed Matter Festival in Warsaw

March 31st is the abstract deadline for the 23rd General Conference of the EPS Condensed Matter Division, which this year will take place from August 30th to September 3rd in Warsaw.

The CMD General Conference is one of the largest and longest established EPS meetings, with recent meetings attracting large attendances to Rome (2008), Dresden (2006) and Prague (2004). The conference highlights the overall strength of the condensed matter community, with symposia and plenary talks devoted not only to subject areas such as magnetism, superconductivity and semiconductors but also cross-cutting topics such as nanosciences and areas where condensed matter plays an increasing role, such as biological physics and the life sciences. The 2010 EPS Europhysics Prize for Outstanding Achievement in Condensed Matter Physics will also be awarded at the meeting, including a plenary talk by the prize winner. This award is acknowledged internationally as one of the most prestigious awards for condensed matter physics - many Europhysics Prize winners have subsequently been awarded the Nobel Prize in recognition of their achievements. In addition, a special symposium is being organised to address teaching of condensed matter physics at both undergraduate and postgraduate level.
The meeting offers an ideal opportunity for young researchers to meet with and present their work to a wide international audience. The confernece is organised under the auspices of the Polish Physical Society and the Rector of the University of Warsaw, Prof. Katarzyna Chalasinska-Macukow. For more information, including registration details, see www.cmdconferences.org or http://cmd23.ipj.gov.pl/.

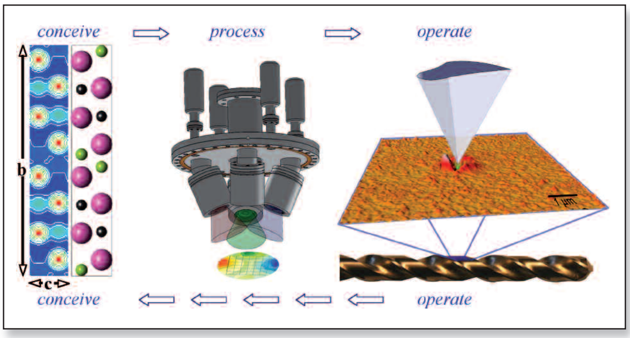
Highlights from europeans journals

APPLIED PHYSICS

Quantum mechanically guided materials design (QMGMD)

QMGMD significantly reduces the development time for materials compared to the conventional materials-development-strategy based on "trial and error" approaches. Present materials for protection of cutting tools, as $Ti_{1-x}Al_xN$, Al_2O_3, c-BN, etc., exhibit high stiffness and hardness. These features are often accompanied by brittle deformation behaviour reducing tool performance and lifetime. One expects that the probability for crack initiation and growth is reduced for materials combining high stiffness and moderate ductility, consequently improving tool performance and increasing tool lifetime.

The calculated elastic properties of Mo_2BC using ab initio methods showed that the bulk modulus of 324 GPa is 45% larger than for $Ti_{0.25}Al_{0.75}N$ and 14% smaller than for c-BN (among the stiffest materials known), indicating a highly stiff material. The calculated bulk-modulus-to-shear-modulus ratio and the positive Cauchy pressure (c_{12}-c_{44}), suggest moderate ductility. Hence, Mo_2BC was identified based on QMGMD to eradicate traditional deficiencies of cutting tool materials.



▲ QMGMD. (Left) Unit cell and charge density plot of Mo_2BC showing covalent (high electron density) and metallic (low electron density) bonding contributions. (Middle) Schematics of combinatorial magnetron sputtering with image showing chemical composition gradient. (Right) Topographical image of a residual indent in Mo_2BC. Significant pile-up (20-50nm in height) around the indent and no visible cracks, suggesting moderate ductility.

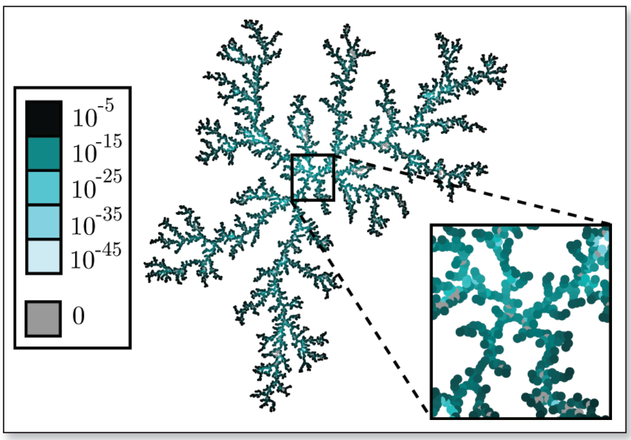
Mo_2BC thin films were synthesized using combinatorial and DC magnetron co-sputtering to validate this prediction. The calculated lattice parameters and Young's modulus agree very well with experiments. Scanning-probe-microscopy of the residual indent (Figure) does not show crack formation and indicates significant pile-up, which is consistent with the moderate plasticity predicted. The apparent contradiction between moderate ductility and indentation hardness values of 29 GPa can be understood by considering the electronic structure thereof, particularly the extreme anisotropy. Stiff Mo-C and Mo-B layers with metallic interlayer bonding enable this intriguing and unexpected property combination. ■

J. Emmerlich, **D. Music**, **M. Braun**, **P. Fayek**, **F. Munnik** and **J.M. Schneider**,
'A proposal for an unusually stiff and moderately ductile hard coating material: Mo_2BC', *J. Phys. D: Appl. Phys.* **42**, 185406 (2009)

CONDENSED MATTER

Measure of **diffusion-limited aggregates**

Geometric fractals are objects which 'look the same' on many different scales and are of theoretical, experimental, and aesthetic interest. A simple stochastic growth model which results in a fractal pattern is Diffusion-limited aggregation (DLA). The DLA growth process involves releasing particles, one at a time, far from a cluster and allowing them to diffuse until they touch the cluster and stick. This forms tenuous random aggregates: see figure. DLA-like structures have been found in systems as diverse as electro-deposition deposits, lightning, and tumor growth. The probability distribution of sticking to the cluster determines the growth process. This distribution is called the *harmonic measure*; it involves a continuous spectrum of scaling exponents. There is no theoretical prediction for the multifractal spectrum of the harmonic measure for DLA. Previous numerical simulations had limited success because complete characterization of the spectrum requires probing the fjords between fingers where the probability to stick is frequently smaller than 10^{-20}. We developed a sampling technique that allowed us to obtain the growth probability for *all* accessible points on the cluster. This technique ("signposting") allowed us to measure probabilities as small as 10^{-80}: they are color-coded on the figure.



▲ The harmonic measure of a DLA cluster with 10^4 particles. lighter colors indicate smaller measure.

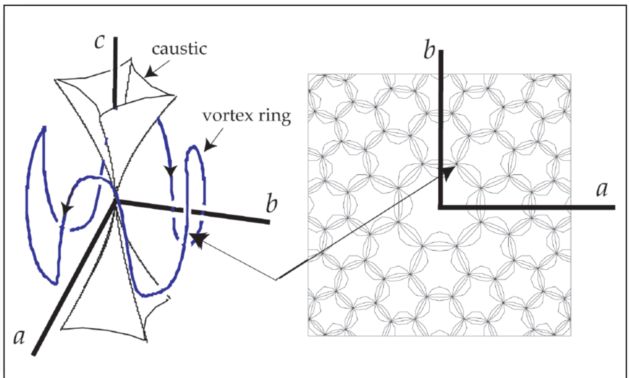
We have verified some conjectures about the form of the multifractal spectrum, specifically a feature which is called a phase transition (in analogy to thermodynamics). We obtained spectra for clusters of different sizes and were able to extrapolate to determine the spectrum for infinitely large clusters. The harmonic measure of other fractal objects has recently been determined using conformal field theory and SLE. The spectra that we determined for these cases can be compared against theoretical results. ■

D.A. Adams, **L.M. Sander**, **E. Somfai** and **R.M. Ziff**, 'The harmonic measure of diffusion-limited aggregates including rare events', *EPL* **87** 20001 (2009)

OPTICS

Structure of a **higher-order diffraction catastrophe**

If a beam of monochromatic light is launched from any initial wavefront that is not plane, it inevitably focuses in bright caustic surfaces – ray-optics features that are classified by catastrophe theory. In this instance the departure of the initial wavefront from a plane has the symmetry of a square. A practical realisation would be the focal region of a thin lens created by a drop of water on a glass slide, with its periphery constrained to be any shape having square symmetry. The bright caustic is always a ribbed double-trumpet with a 45° twist, but its sharpness is softened by diffraction. Thus, in wave optics we have a three-dimensional diffraction field of amplitude and phase that is structurally stable against any perturbation that preserves the symmetry. Mathematically, it is the diffraction catastrophe X_9 with modulus -6, whose germ is x^4-$6x^2y^2$+y^4, and there is a corresponding diffraction integral.



▲ **(Left)** the caustic surrounded by a puckered dislocation (vortex) ring. **(Right)** contours of equal phase in the focal plane ab; interval π/6.

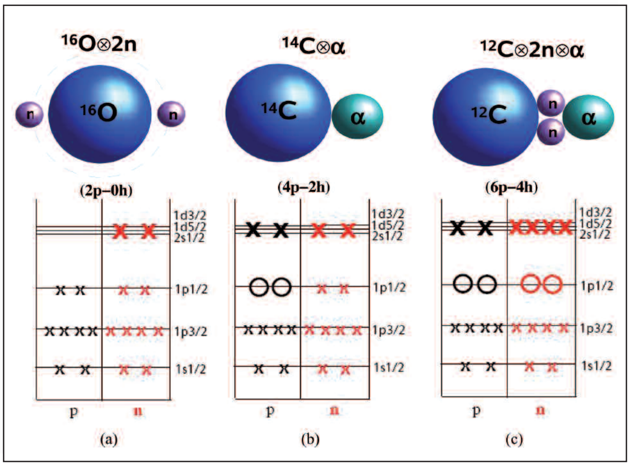
As with all such diffraction catastrophes the essential structure of the field is based on a pattern of line singularities (wave dislocations or optical vortices) on which the amplitude is zero and the phase is indeterminate. The caustic is encircled in the focal plane by a highly puckered, non-circular vortex ring and a forest of other dislocation lines whose intersections with the focal plane are seen as the many points where all the equiphase contours come together. The 4-fold symmetry of the whole pattern contrasts with the local 3-fold symmetry displayed in the hexagons. Inside the caustic there is a beautiful 4-fold symmetric lattice of small puckered dislocation rings. It is remarkable that all this intricate detail should lie concealed within a simply written diffraction integral. ■

J.F. Nye, 'Wave dislocations in the diffraction pattern of a higher-order optical catastrophe', *J. Opt.* **12**, 015702 (2010)

NUCLEAR PHYSICS

Molecular and cluster structures in ^{18}O

The cluster model has been used to describe certain states of selected nuclei as clusters of lighter nuclei, which, because they are particularly stable, retain some of their identity in a molecular state. For instance, when excited in a particular way a carbon nucleus can take up a structure like three alpha-particles while a magnesium nucleus can exist as two orbiting carbon nuclei - in effect, a "nuclear molecule". The present authors have recently discovered that heavier N=Z alpha-conjugate nuclei, such as ^{36}Ar, ^{56}Ni and ^{60}Zn, may have ternary decays from extremely deformed collinear shapes. Alpha-clustering was fairly well illustrated 4 decades ago by the Ikeda diagram for N=Z nuclei.



▲ **Schematic illustration of three possible cluster and shell structures in ^{18}O. The structure on the right requires a (6p-4h) excitation in the shell model and a "molecular" configuration with two valence neutrons in the cluster model.**

Based upon complete spectroscopy measurements of beryllium and carbon isotopes performed by the present collaboration, von Oertzen has proposed an extension of the Ikeda diagram to picture neutron-rich nuclei with alpha-particles and ^{16}O nuclei as basic clusters. The present article on molecular structures in ^{18}O and forthcoming investigations of more exotic neutron-rich oxygen isotopes (figure) will necessitate revision of this extended Ikeda diagram to include the strongly bound ^{14}C nucleus as a basic cluster by analogy to ^{16}O.

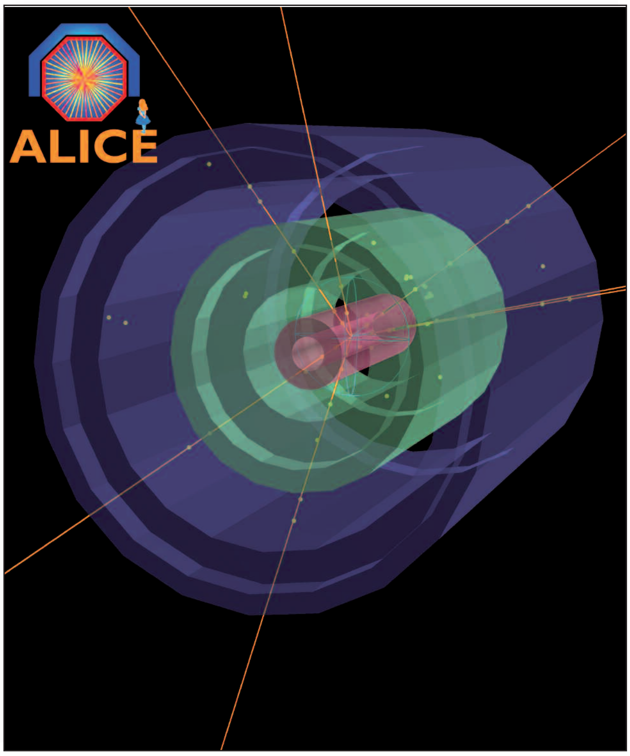
Nuclear clustering has an important bearing on energy production in stars and the abundance of the elements, since the rate at which nuclei are produced in stars and supernovae is profoundly influenced by their structure. Therefore, further spectroscopic exploration at Radioactive Ion Beams facilities, such as GANIL-SPIRAL2, RIKEN-RIBF, FAIR, FRIB and EURISOL, will have to be undertaken to discover new surprising clusters (*e.g.* nuclear polymers) in exotic nuclei far from the stability line. ■

W. von Oertzen, T. Dorsch, H.G. Bohlen, R. Krücken, T. Faestermann, R. Hertenberger, Tz. Kokalova, M. Mahgoub, M. Milin, C. Wheldon and **H.-F. Wirth**, 'Molecular and cluster structures in ^{18}O', *EPJ A* **43**, 17 (2010)

PARTICLE PHYSICS

First proton-proton collisions at the LHC seen with ALICE

On 23rd November 2009, during the early commissioning of the CERN Large Hadron Collider (LHC), two counter-rotating proton bunches were circulated for the first time concurrently in the machine, at the LHC injection energy of 450 GeV per beam, allowing all LHC experiments to report first collision candidates.



284 such candidates were recorded by the ALICE experiment, allowing the events to be immediately reconstructed and analyzed. The results obtained by measuring the spatial distribution (specifically, the pseudorapidity density) of charged primary particles in the central region, were found to be consistent with previous measurements in proton-antiproton interactions at the same centre-of-mass energy at the CERN SppS collider (UA5 Collaboration, G.J. Alner *et al.*, *Z Phys. C* **33** (1986) DOI 10.1007/BF01410446).

Figure shows the first pp collision candidate by the event display in the ALICE counting room (3D view).

J. Schukraft, the ALICE spokesman, said: This important benchmark test illustrates also the excellent functioning and rapid progress of the LHC accelerator, and of both the hardware and software of the ALICE experiment, in this early start-up phase.

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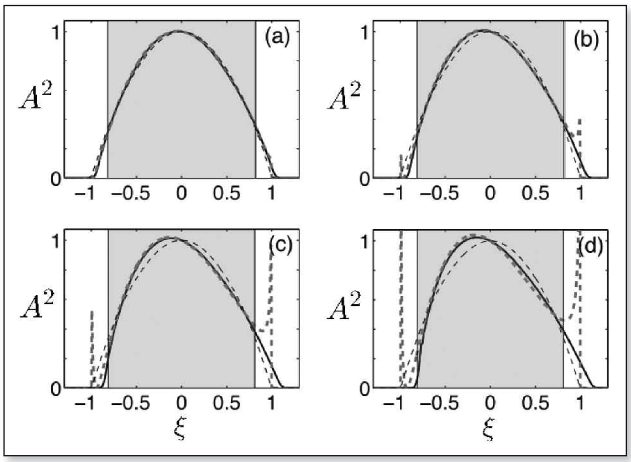
The ALICE Collaboration (K. Aamodt *et al.* – 1040 co-authors), 'First proton-proton collisions at the LHC as observed with the ALICE detector: measurement of the charged particle pseudorapidity density at √s=900GeV', *Eur. Phys. J. C* **65**, 111 (2010)

OPTICS

Fibre effect on parabolic optical pulses

A fundamental process in nonlinear optics of recent interest is the self-similar dynamical effects in nonlinear pulse propagation in optical fibres with gain and normal group-velocity dispersion. Recent results have demonstrated a fundamentally new operating regime where nonlinear propagation is exploited to generate a particular class of pulses with a parabolic intensity profile and a linear frequency chirp (phase characteristic) that evolve self-similarly. Such pulses occur in high-power femto-second lasers, spectral broadening and super-continuum generation and have a variety of photonic applications. However, many experimental settings show that it is important to consider the impact of higher-order dispersion on the pulse evolution. In this work, we develop a perturbation analysis that describes the effect of third-order dispersion (TOD) on the self-similar parabolic pulse solution of the propagation equation in a gain fibre. Exploiting the smallness of the ratio of the pulse temporal width to the peak amplitude, analytic expressions for the leading order perturbations in the amplitude and phase of the pulse are derived, and are well approximated by cubic polynomials in the temporal variable. The figure shows clearly that the TOD makes the pulse shape become asymmetric with the peak shifted to the leading edge. As the propagation distance increases, the asymmetry becomes stronger. The theoretical model (dashed grey curves) predicts with sufficient accuracy the pulse structural changes induced. In addition to the pulse perturbations, the skewness that is typically used to quantify the asymmetry of the pulse temporal shape is explicitly calculated in terms of the system parameters.



▲ **Typical pulse temporal intensity profiles at four points along a gain fibre with (solid black) and without (dashed black) third order dispersion (TOD)**

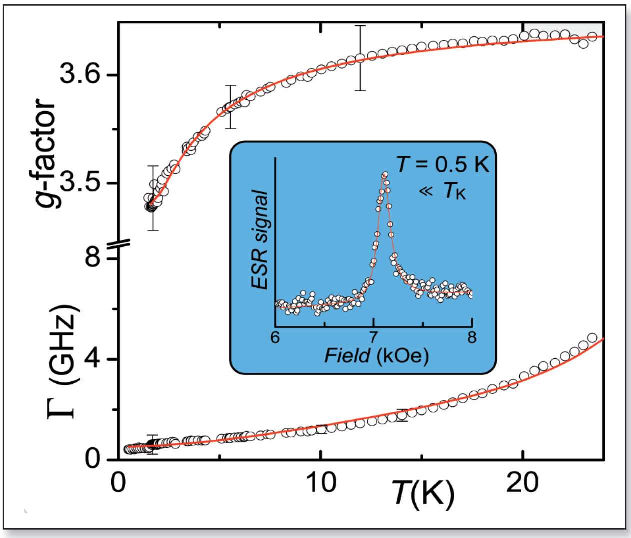
We have verified some conjectures about the form of the multifractal spectrum, specifically a feature which is called a phase transition (in analogy to thermodynamics). We obtained spectra for clusters of different sizes and were able to extrapolate to determine the spectrum for infinitely large clusters. The harmonic measure of other fractal objects has recently been determined using conformal field theory and SLE. The spectra that we determined for these cases can be compared against theoretical results. ■

▮▮▮ **B. G. Bale** and **S. Boscolo**, 'Impact of third-order fibre dispersion on the evolution of parabolic optical pulses', *J. Opt.* **12**, 015202 (2010)

CONDENSED MATTER

Kondo effect can help to see **Electron Spin Resonance**

The discovery of electron spin resonance (ESR) in the heavy fermion Kondo lattice $YbRh_2Si_2$ at temperatures well below the thermodynamically measured Kondo temperature T_K = 25 K (J. Sichelschmidt *et al.*, *Phys. Rev. Lett.* **91**,156401, 2003) became a great surprise for the condensed matter physics community. According to a common belief the Kondo effect prevents the observation of the ESR of paramagnetic impurities in metal: at T< T_K the conduction electrons should screen their magnetic moment and their spin relaxation rate Γ_K toward the equilibrium conduction electrons sufficiently exceeds the ESR frequency. In a simple approximation Γ_K logarithmically diverges at the temperature approaching to T_K from above. However, these arguments are correct only for a single-ion picture of the Kondo effect. In the case of a high concentration of the paramagnetic impurities and especially for the Kondo lattice the back influence of the Kondo-ions on the spin dynamics of the conduction electrons becomes very important.



▲ **An intrinsic ESR signal of $YbRh_2Si_2$ is surprisingly seen well below the Kondo temperature T_K. Linewidth Γ and g-factor of the ESR signal can be well described by a collective spin mode of Yb spins and conduction electron spins in the presence of the Kondo effect (red lines).**

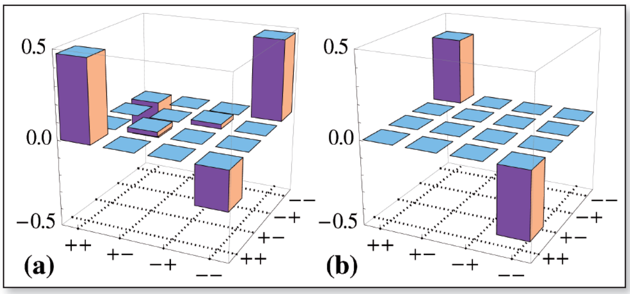
The equations of motion for both spin systems are coupled by additional kinetic coefficients, which diverge on the same energy scale: a collective spin mode is formed and is supported by the Kondo effect. The mutual cancelation of all divergences results in a greatly reduced effective linewidth even in the case of a strongly anisotropic Kondo interaction. An additional reduction of the ESR linewidth comes from the motional narrowing of the local magnetic field distribution caused by the quasilocalized f-electrons. ■

▮▮▮ **B.I. Kochelaev**, **S.I. Belov**, **A.M. Skvortsova**, **A.S. Kutuzov**, **J. Sichelschmidt**, **J. Wykhoff**, **C. Geibel** and **F. Steglich**, 'Why could electron spin resonance be observed in a heavy fermion Kondo lattice?', Eur. Phys. J. B 72, 485 (2009)

QUANTUM PHYSICS

Entanglement in the case of **microcavity polaritons**

The concept of entanglement played a crucial role in the development of quantum physics. It has gained renewed interest in quantum information/computation, as a precious resource enabling to perform tasks that are impossible or inefficient in the classical realm. Scalable solid-state devices will make use of local electronic states to store quantum correlations. Polaritons, as hybrid states of electronic excitations and light, are the most promising solution for generation and control of quantum correlations over long range. In order to address quantum coherence properties and entanglement in solid-state quantum systems, the preferred experimental situation is the few-particle regime. Noise, however, represents a fundamental limitation, as it tends to lower the degree of non-classical correlations or even completely remove it.



▲ (colour online) a(b) Example of tomographic reconstruction for the real (imaginary) part of the density matrix from which we quantify the degree of entanglement of the mixed generated state for different experimental cases.

Here we show theoretically that polariton pairs with a high degree of polarization entanglement can be produced through parametric scattering. It can emerge in coincidence experiments, even at low excitation densities where the dynamics is dominated by incoherent photoluminesce. We model the polariton parametric process, producing entanglement, and the time evolution of the competing decoherence processes, using a microscopic time-dependent theory. We show how a tomographic reconstruction, based on two-times correlation functions, can provide a quantitative assessment of the level of entanglement produced under realistic experimental condition. Our study provides a suggestive perspective towards hybrid all-optical quantum devices where quantum information can be efficiently generated and controlled within the same structure. This result puts forward the robustness of pair correlations in solid-state devices, even when noise dominates one-body correlations. ■

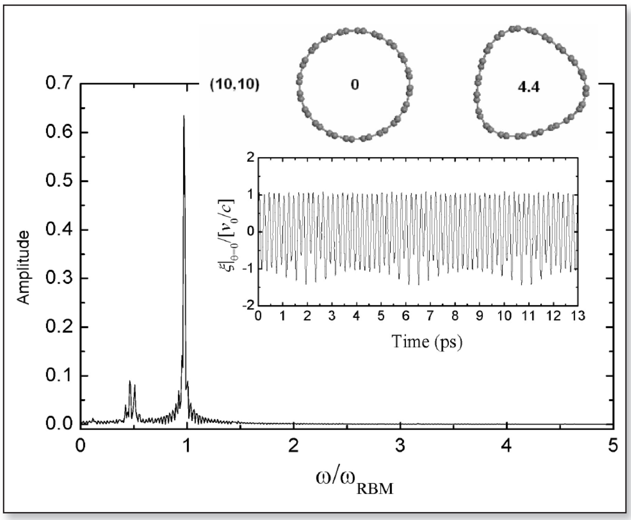
S. Portolan, **O. Di Stefano**, **S. Savasta** and **V. Savona**, 'Emergence of entanglement out of a noisy environment: The case of microcavity polaritons', *EPL* **88**, 20003 (2009)

CONDENSED MATTER

Automated vibration mode transformations in nano-structures

Intermittent mode transformations between radial breath mode (RBM) and other lower frequency flexural modes may occur in carbon nano-tubes when certain conditions are satisfied. Such a transformation is related to 2:1 or 1:1 internal resonance, which is normally observed in continuum structures. This phenomenon has been shown in our recent MD and continuum shell simulations. A nonlocal model provides a more efficient way to demonstrate this phenomenon with higher accuracy than the local continuum model.

Theoretically, when the initial RBM velocity or maximum displacement of a circular nano-structure (nano-tubes, nano-rings, etc.) is greater than a critical value, the subsequent vibration may be transformed to a lower frequency flexural mode. Such mode transformations may carry on intermittently between RBM and flexural modes without requiring further energy input. It is found that this intermittent mode transformation is controlled by a nonlinear differential equation (Mathieu equation) and the Mathieu stability diagram can approximately describe the parameters influencing the mode transformation.



▲ Automated mode transformation between RBM and 3[rd] flexural mode of armchair (10,10) expressed by their mode shapes and amplitudes in time and frequency domains

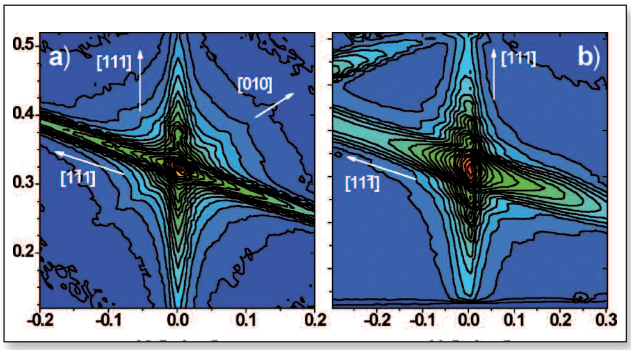
It is interesting to observe the mode transformation phenomenon in nano-scale structures because a similar phenomenon has been reported as 2:1 or 1:1 internal resonance in macroscopic structures. Since the optical and electrical properties of a nano-structure are closely related to their vibration characteristics, it opens up the way to explore the implications of this finding in the applications of nano-structures as nano-scale sensors, transistors, oscillators etc. We look forward to seeing real experimental evidence of this phenomenon in nano-structures. ■

M.X. Shi, **Q. M. Li** and **Y. Huang**, 'Nonlocal shell model for mode transformation in single-walled carbon nano-tubes', *J. Phys.: Condensed Matter* **21**, 455301 (2009).

CONDENSED MATTER

X-ray characterization of **epi-Ge / Pr_2O_3 / Si(111) films**

The concept of so-called engineered silicon (Si) wafer substrates is a new approach to integrate alternative semiconductor layers on the technologically mature silicon material. Germanium (Ge), for example, may act as a template for the integration of A_3B_5 materials to allow a combination of micro and optoelectronics on one chip. Different approaches to realize this are under investigation. We studied the heteroepitaxial growth of Ge on Si(111) using the rare earth oxide Pr_2O_3 as buffer material with the task to isolate the top semiconductor layer from the substrate, to accommodate lattice parameters, and to act as a diffusion barrier. Typical epi-Ge/Pr_2O_3/Si(111) layer structures have a buffer layer thickness between 7 and 10 nm and epi-Ge layers ranging in thickness from a few nanometres to 1 µm.



▲ Reciprocal space maps near the (a) Ge (11$\bar{1}$) and (b) oxide (2$\bar{2}$2) (b) oxide EMBED Equation.3 reflection measured in defect sensitive planes under grazing incidence conditions with $\alpha_i = 0.6°$.

One of the key problems of such layer systems is the structural perfection of the top layer. X-ray techniques offer the possibility of a rather fast and non-destructive characterization. This can be done either with laboratory-based equipment or even better at a synchrotron, where the unique features of synchrotron radiation offer perfect conditions for a defect characterization of the top Ge layer as well as the buried very thin oxide layer.
The paper presents results obtained at the European Synchrotron Radiation Facility (ESRF) by grazing incidence X-ray diffraction under different angles of incidence a_i. Especially reciprocal space maps at selected lattice points allow a complex characterization of defects in the whole layer stack. This knowledge offers new possibilities for a further optimisation of growth conditions. ■

▮▮▮ **P. Zaumseil**, **A. Giussani**, **P. Storck** and **T. Schroeder**, 'Synchrotron X-ray characterization of epi-Ge / Pr_2O_3 / Si(111) layer stacks', *J. Phys. D: Appl. Phys.* **42**, 215411 (2009)

OPTICS

Light-pulse atom interferometry in microgravity

Up to now, the more accurate inertial measurements took advantage of the wave nature of light that leads to the interference phenomenon. Nevertheless, thanks to the laser cooling of atoms, it is now possible to produce interference between matter waves to exceed the sensitivity of optical measurements. Because the atoms have a mass, these new "quantum sensors" are remarkably sensitive to the effects of gravitational force or inertial forces.

▲ Picture of the airbone "inertial quantum sensor" experiment during a weightlessness parabola of the last campaign in October 2009, in the NOVESPACE 0-g airbus. The atom sensor is the box at the low left corner. The main rack is used for the laser sources and monitoring of the experiment.

Nevertheless, on earth, gravity pulls the atoms downward and the measurement time and thus the accuracy of the inertial measurement is limited by free fall time of the atoms. To beat this limit, physicists plan to make atomic interferometers in space, in 0-gravity. A first step in this direction has been taken by a joint team, formed by two CNRS laboratories at the Institut d'Optique and the Observatoire de Paris and ONERA, who has observed for the first time interference fringes in an airborne atom interferometer in microgravity. Thanks to the support of CNES and ESA, the physicists have developed a prototype that can be embedded, and is therefore much more compact and reliable than the usual laboratory experiments. With this prototype "inertial quantum sensor", they even recently recorded the airplane acceleration while in weightlessness. This work is a necessary first step to create a device, which at the end of several stages of development will be finally launched into space for example for gravity monitoring or for tests of fundamental physics. ■

▮▮▮ **G. Stern**, **B. Battelier**, **R. Geiger**, **G. Varoquaux**, **A. Villing**, **F. Moron**, **O. Carraz**, **N. Zahzam**, **Y. Bidel**, **W. Chaibi**, **F. Pereira Dos Santos**, **A. Bresson**, **A. Landragin** and **P. Bouyer**,
'Light-pulse atom interferometry in microgravity', *Eur. Phys. J. D* **53**, 353 (2009)

Y. Couder [1], A. Boudaoud [2], S. Protière [1] and E. Fort [3]

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WALKING DROPLETS

A FORM OF WAVE-PARTICLE DUALITY AT MACROSCOPIC SCALE?

A droplet bouncing on the surface of an oscillating liquid may couple with the surface waves it generates and thus start to propagate. The resulting "walker" is a coherent macroscopic object that associates the droplet and its waves. Due to their waves, the mutual interactions of these walkers, as well as their reactions to their environment have surprising assets.

Masses and waves have long been the constitutive elements of classical physics. The wave-particle duality, which characterizes the behaviour of elementary physical objects on a microscopic scale, appeared only with quantum mechanics [1]. Until now, this duality had no equivalent at the macroscopic scale, for which masses and waves are different objects. We have recently introduced, in classical physics, a system that couples a material particle and a wave. It exhibits surprising properties and some of its observed features can be compared to those attributed to the wave-particle duality in quantum mechanics. The simple fact that such a comparison is possible (in spite of large differences) is in itself a surprise.

▲ Falling drops of water. © iStockPhoto

Bouncing droplets and surface waves

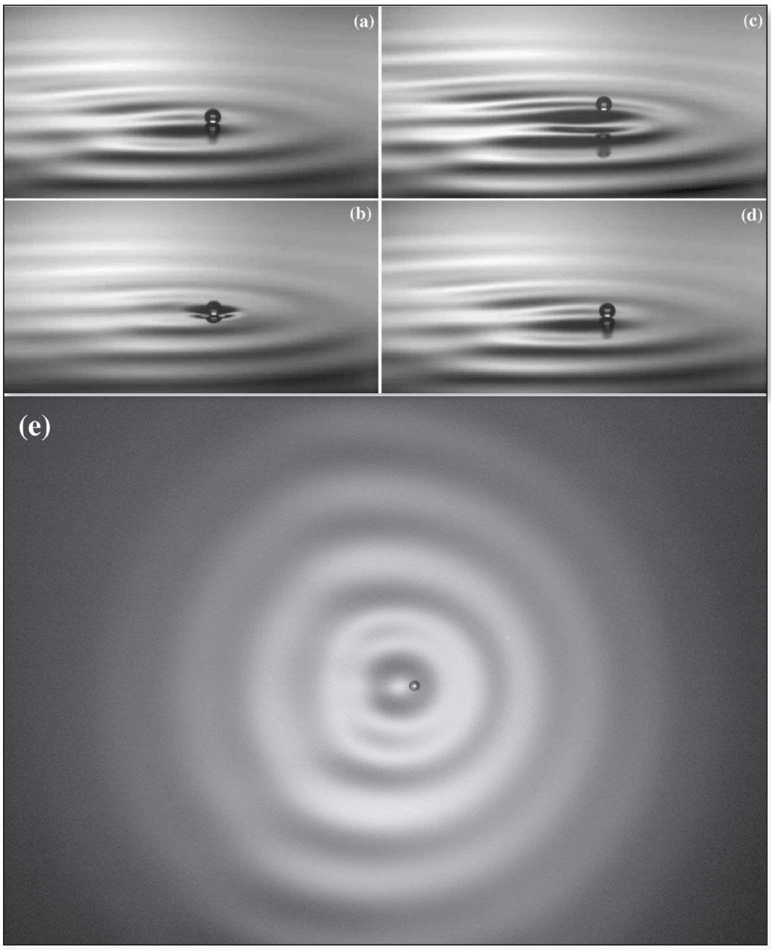
Our working tool is a droplet bouncing on a bath of the same liquid, and which becomes dynamically associated with the surface wave it emits.

Before presenting its properties, we shall first describe the conditions for the existence of this new system. Normally a liquid drop falling on the surface of the same liquid disappears rapidly (a few tenths of a second). In a first step [2], we have shown that this coalescence may be inhibited when the bath is made to vibrate vertically with a characteristic acceleration exceeding g, the acceleration of gravity. This causes the drop to bounce on the surface periodically. As the droplet collides with the interface, it remains separated from it by a continuous air film. Before this air film has had the time to break, the drop lifts off again. A silicone oil droplet of millimetre size can thus be maintained for an unlimited time in a kind of "oscillating levitation" on the liquid surface.

At each successive bounce, the drop generates a surface wave similar to that caused by a stone thrown into water. Generally, this wave is strongly attenuated. However, when the amplitude of the forced oscillation is increased, the amplitude and spatial extension of the waves become larger. A remarkable transition is then observed [3, 4]: the drop starts to move horizontally at a speed V_W along the fluid surface. Henceforth, the set "drop plus associated wave" will be called the "walker". Pictures of such a walker are shown in Fig.1.

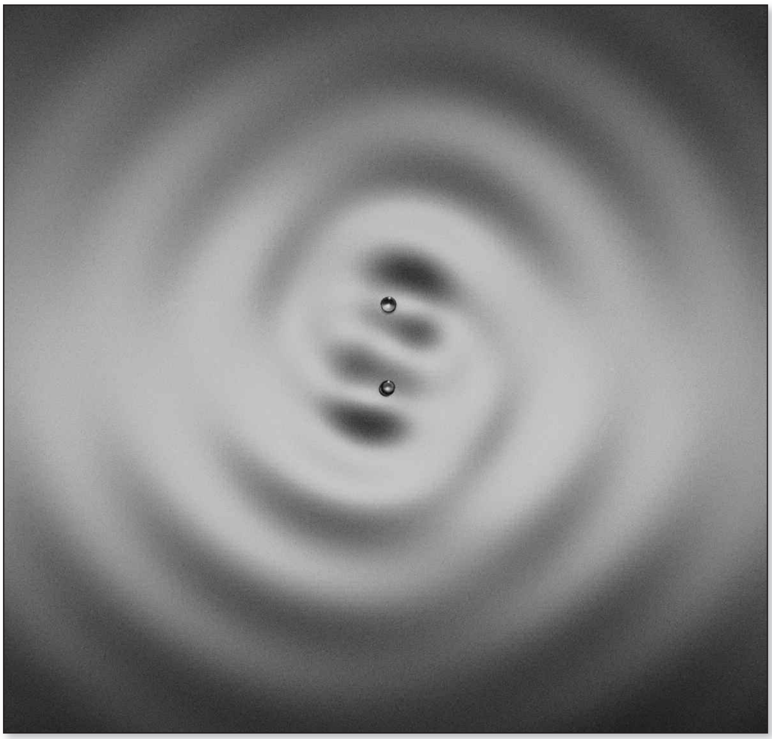
The spontaneous horizontal displacement results from the interaction of the drop with the surface waves. To understand this, one has to remember that a liquid surface is potentially unstable when it is submitted to vertical oscillations. For large oscillating amplitudes, the liquid surface spontaneously forms a system of stationary waves at a frequency $f/2$, the first sub-harmonic of the forced oscillation. This instability [5, 6], discovered by Faraday in 1831 (see box), appears when the acceleration amplitude γ_m of the forced oscillation becomes larger than a threshold value. In our experiment, when the forced oscillation amplitude is below but close to this threshold, the vertical bouncing motion also becomes sub-harmonic so that the droplet collides with the surface only once in two periods of the forced oscillation. The drop becomes an efficient generator of Faraday waves of frequency $f/2$ that are very weakly damped due to the proximity of the instability threshold.

As the drop rebounds on a wave-perturbed surface, there is a spontaneous "breaking of symmetry" by which the droplet starts moving horizontally on the interface. Fast camera recordings show that in this regime, at each bounce, the drop hits the forefront of the central bump of the wave created by the previous shocks (Fig.1). Besides the usual vertical kick, this shock on a locally inclined surface gives the drop a horizontal kick that will be repeated at the next period. On the average this results in a mean force, generating the motion. Because of nonlinear saturation, the droplet reaches a constant limit speed V_W that is of the order of a tenth of the phase velocity V_ϕ of the surface waves ($V_W = 20$ mm/s and $V_\phi = 189$ mm/s for a frequency $f/2 = 40$ Hz). The "walker" is a coherent object, which exists only through the association of the wave and the droplet. If the drop coalesces with the bath, the wave vanishes. Inversely, if the waves are damped (for example in regions where the liquid layer is thin), the drop stops travelling. In the following experiments, the properties given to these walkers by the non-local character of their waves are explored. We will successively describe



▲ **FIG. 1:** (a-d) Four successive pictures of a walker, side view; (e) top view. Photographs a and d were taken when the droplet touches the surface on the slope of the central bump of the wave generated by the previous collisions. The droplet diameter is approximately 0.7 mm.

▼ **FIG. 2:** Two orbiting walkers. The picture was taken when the two droplets touch the surface. Droplets diameter: 0.7 mm; orbit diameter: 3.7 mm.

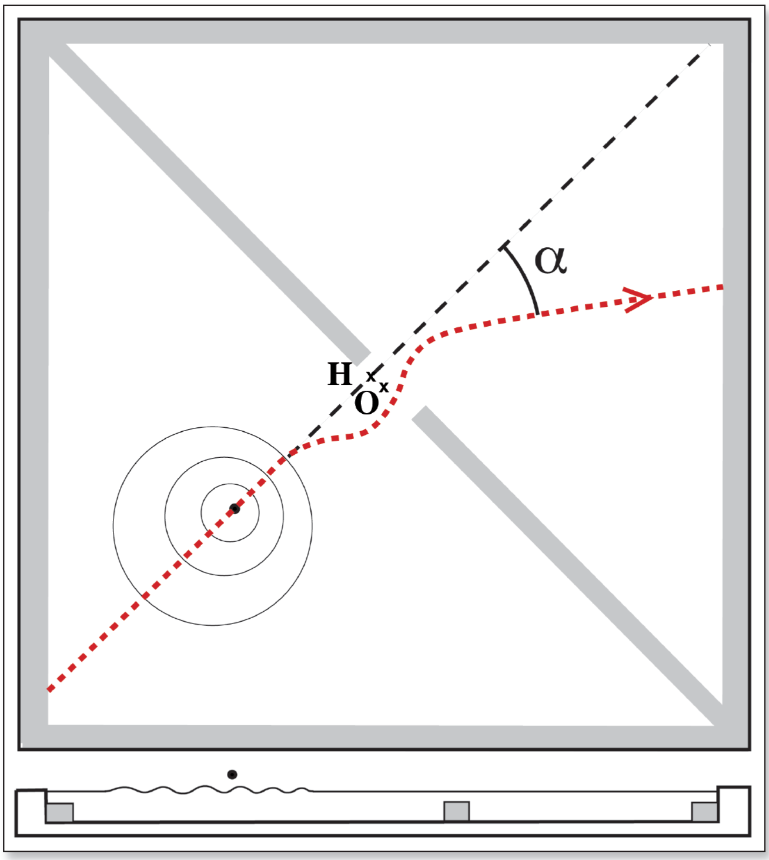


the way a walker reflects from a wall, the interaction between several walkers, and finally the diffraction and interference of single walkers passing through slits.

Reflection from a wall

Walkers are observed to be reflected by the boundaries of the bath somewhat like billiard balls. Here, however, the trajectory has no sharp reflection point; the deflexion is gradual and the droplet follows a curved trajectory, the distance of closest approach being on the order of the Faraday wavelength. Remember that the droplet moves because it bounces off the slanted surface of its own wave. However, close to a boundary, the local slope of the interface results from the superposition of the waves recently emitted by the droplet with earlier waves that have been reflected by the wall. This effect provokes a slight change of direction at each rebound and gradually bends the trajectory of the drop. This is an evidence of an "echolocation" of the walkers. The waves emitted earlier and having propagated faster than the walker itself, come back towards the droplet carrying information on the geometry of the borders. The walker avoids the nearing obstacle as a dolphin or a bat would do, even though it has no brain to process the signal.

▼ **FIG. 3: Experimental set-up for the study of walkers diffraction as seen from top and in cross section. The sketch also shows the droplet trajectory (red dotted line). *O* is the centre of the slit and *H* the point where the droplet would have crossed the slit if its trajectory had remained straight (dashed line). The impact parameter *Y* is the distance *OH* and *L* the width of the slit $-L/2 \leq Y \leq L/2$.**



Interaction of two walkers

When several walkers coexist on the same bath, they are observed to have long-distance interactions [3, 4] due to the interference of their waves. In order to characterize this interaction, we organized controlled "collisions" between two identical walkers moving initially towards each other along straight parallel trajectories. The distance d between these lines defines, as usual, the impact parameter of the collision (d is larger than the droplet size so that there is never real contact between the drops).
We find that, depending on the value of d, the interaction is either repulsive or attractive. When repulsive, the drops follow two approximately hyperbolic trajectories. When attractive, there is usually a mutual capture of the two walkers into an orbital motion similar to that of twin stars (fig.2). Allowed orbits have diameters d_n^{orb} quantified by the Faraday wavelength as $d_n^{orb} = (n\text{-}\varepsilon)\lambda_F$ with $n = 1, 2, 3\ldots$ if the droplets bounce in phase, and $n = 1/2, 3/2, 5/2\ldots$ if they bounce in opposite phases. The shift ε is a constant: $\varepsilon = 0.2$.
In all cases of interaction, the local slope on which one of the droplets bounces results from the superposition of its own wave with the wave generated by the other. The speed of each droplet in its orbit is mostly determined by the interaction with its own wave. Its orbital motion results from the interaction with the other walker and requires an effective attractive force. The observed diameters d_n^{orb} correspond to those distances where, at each collision with the surface, each droplet falls on the internal edge of the circular wave produced by the other (Fig.2). These collisions give each droplet a kick directed towards the other. Repeated collisions thus provide the centripetal force needed for the orbital motion.

Diffraction and interferences of single walkers

The previous experiments have shown that a walker is the association of a localized massive object with a wave that governs its interaction with the external world (cell boundaries, obstacles, other walkers etc…). How can this "particle" and this wave have common dynamics? In particular, what is the trajectory of the droplet when its associated wave is diffracted [7]? As explained above, a linear strip of metal stuck to the bottom of the cell, thus reducing the liquid layer thickness, creates for the walker the equivalent of a wall (Fig.3). An opening of width L in the middle of the strip will be a narrow passage for a walker. As it passes through, its associated wave will be diffracted. Successive images of a walker passing a slit at normal incidence are shown in Fig.4. Is the observed deviation deterministic? In such a case it should depend on the position Y at which the droplet passes the slit. Measuring the deviation angle α far from the slit as a function of Y shows random results. The same walker, crossing the slit at the same place, may deviate toward one side or the other (Fig.5a). Repeating the experiment with the same walker crossing the slit several times, it appears that some values of the deviation angle are more frequent than others. To make this observation quantitative, a histogram of α is shown in Fig.5b for an approximately uniform distribution of the impact parameter Y. Most walkers are in the central lobe of angular width λ_F/L and surrounded by secondary peaks. The envelope of the histogram looks like the amplitude of a plane wave of wavelength λ_F when diffracted by a slit of width L (Fig.5b).

The analogy with Young's double slit experiments can then be investigated by creating two neighbouring slits through the wall. At each crossing the droplet is observed to pass through either one of the slits. However, its associated wave passes through both slits, thus generating interferences that guide the particle. The observed deviation histogram looks like the interference diagram of a plane wave of wavelength λ_F, propagating through two slits of width L at a distance h.

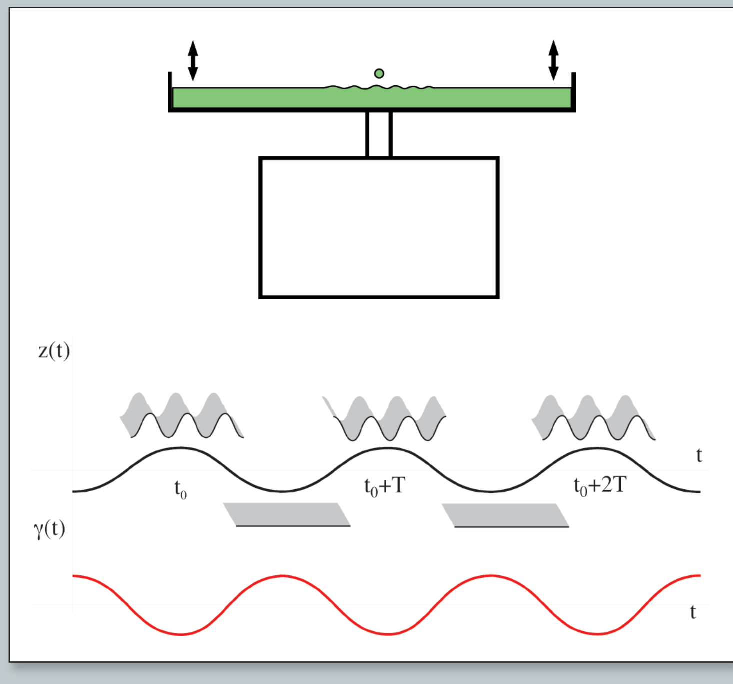
Using a single walker, diffraction and interference patterns are thus obtained here in a cumulative histogram of independent events. Among the experiments that demonstrated the founding paradoxes of quantum mechanics, an essential one concerns the interference with a very weak flux of particles. The first one [8] is due to G.I. Taylor in 1909. It showed that, after a sufficient exposure time, an interference pattern was observed behind Young's slits even when only one single photon was present in the system at a time. The pattern was the result of a statistical behaviour of the photons. The same result was then observed for electrons [9]. The Feynman lectures [1] present a thorough discussion of this effect and of its quantum interpretation in which the probability wave of each particle crosses the two slits at the same time. Surprisingly, we recover a similar behaviour in our system.

To conclude, it is useful as a *caveat* to remember the differences between the present experiments and those on the usual wave-particle duality at the quantum scale.

- The most evident is that, at the macroscopic scale, the Planck constant does not show up.
- The present system is highly dissipative while the quantum situation is non-dissipative.
- The system is two-dimensional.
- The wave is emitted by the particle and propagates at a fixed velocity on a material medium.
- The measurements made on the walkers do not perturb their behaviour. So, the position of the droplet can be observed anytime during interference experiments and the slit it crosses is known. However, this unperturbed observation could be impaired if the measurements had to be done using surface wave detectors only.

Experimental conditions and Faraday instability

In the present experiments a small cell containing a liquid is subjected to a vertical sinusoidal acceleration $\gamma = \gamma_m \cos\omega_0 t$. The liquid is a silicon oil 20 times more viscous than water. The oscillation frequency is 80 Hz and the acceleration amplitude γ_m between g and $5g$. The bouncing of the droplets, with diameters in the mm range ($0.5<D<1.5$ mm), is observed. For acceleration amplitudes $\gamma_m > g$, coalescence of the droplets with the surface no longer occurs. Beyond a threshold $\gamma_m^F = 4.5g$, the Faraday instability (10) is observed and the liquid surface becomes covered with a surface waves network.



It is known since the work of Faraday (10) in 1831 that a liquid surface becomes unstable when subjected to vertical oscillations of sufficient amplitude. In general, a network of stationary waves oscillating at half the forced oscillation frequency is observed. This effect results from what is called parametric forcing, the liquid being submitted to a modulated effective gravity.

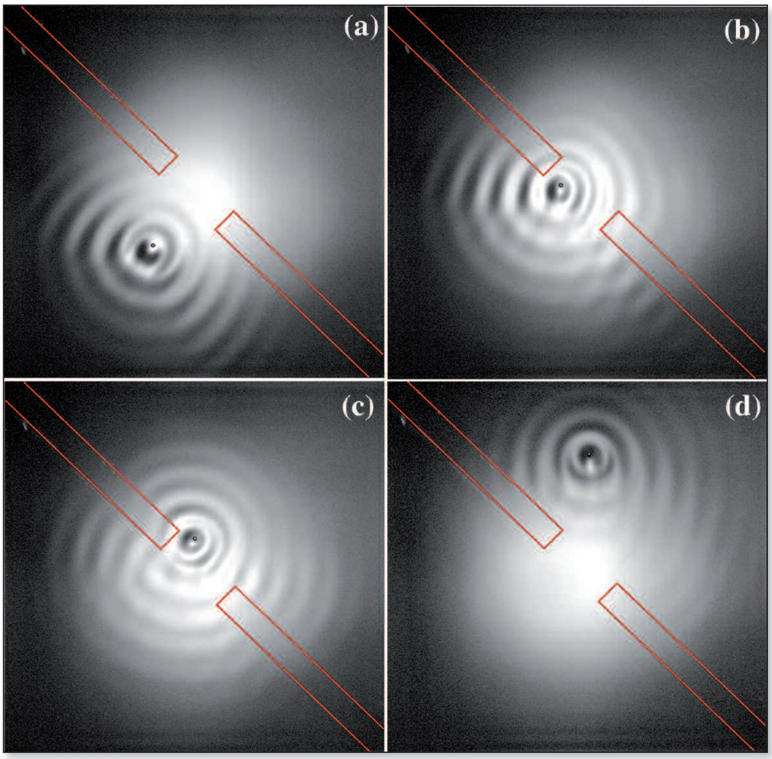
The drawing below shows the oscillation $z(t)$ of the vertical position of the cell and its acceleration $\gamma(t) = \gamma_m \cos 2\pi t/T$ (where T is the forced oscillation period). The sketches in grey show the physical aspect of the liquid surface at different times. At $t = t_0, t_0+T, t_0+2T, \ldots$ the substrate acceleration has the same sign as gravity, but is larger. At these times, some parts of the liquid surface lag behind and periodic crests form spontaneously. At t_0 and t_0+T, maxima and minima are exchanged. Inversely, at $t = t_0+T/2, t_0+3T/2, \ldots$, the substrate acceleration opposes gravity and flattens the surface. The interface deformation is therefore periodic and its period is twice the forcing one.

The vertical motion of the droplets is also forced by the substrate acceleration $\gamma(t)$. The droplet leaves the surface at each oscillation when the downward acceleration of the substrate becomes larger than g. For γ_m values slightly larger than g, the droplet has a short free flight at each period. Nearing the Faraday threshold, $\gamma_m < \gamma_m^F$, the droplets have a free flight of such amplitude that they touch the surface only once in two oscillations. Their motion then has the same period $2T$ as the Faraday waves. Since this type of bouncing occurs immediately below the Faraday instability threshold, the droplets become localized emitters of weakly damped Faraday waves and become "walkers".

Keeping these differences in mind, we can now consider the similarities.

- The wave-induced interactions have been shown to impose quantified diameters to the stationary orbits.
- The diffraction and interference experiments have shown that the transverse momentum of the walker becomes ill-defined when the transverse amplitude of its wave is limited. The diffraction, which is intrinsically bound to the Fourier transform of the wave, is transformed here into an uncertainty of the motion of the droplet.
- Recent experiments (10), not included in this paper, have shown that walkers have a non-zero probability of crossing opaque barriers, a phenomenon reminiscent of the quantum tunnel effect.

All observed phenomena are related to the particle-wave interaction. The droplet moves in a medium modified by previously generated waves. As the droplet moves, the points of the interface it visits keep emitting waves. The wavefield has thus a complex structure that contains a "memory" of the path. More work is needed to fully understand this type of spatial and temporal non-locality. ■



▲ **FIG. 4:** Four successive pictures, a to d, of a walker moving through a slit.

▼ **FIG. 5:** (a) Measured values of individual deviations α as a function of impact parameter *Y*. The Faraday wavelength is here $\lambda_F = 4.75$ mm and the slit width L=14.7 mm.
b) Histogram of measured deviations for N=125 successive crossings of single walkers through a slit in the same conditions as in (a). The system being symmetrical with respect to the slit axis, the statistics are improved by adding to each trajectory its symmetric counterpart. The shape of the histogram looks like the diffraction amplitude of a plane wave of the same wavelength crossing that slit (aperture ratio L/λ_F =3.1).

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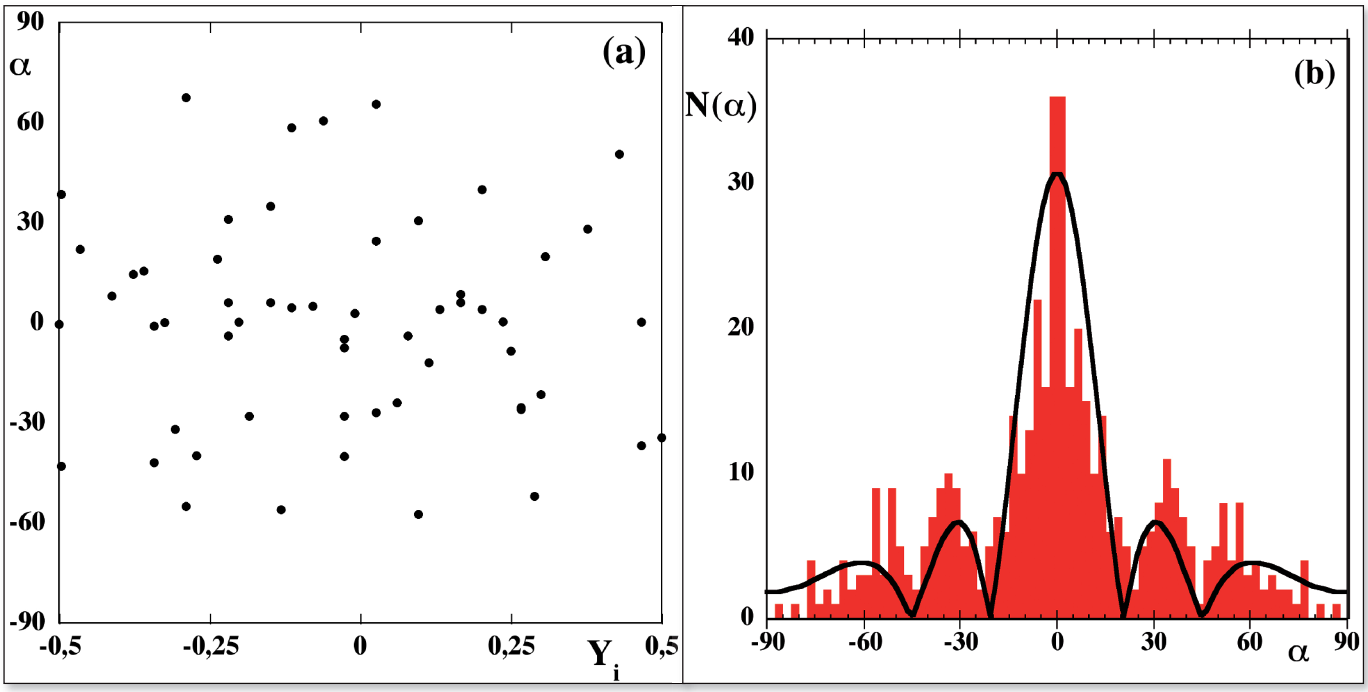

FRONTIERS OF QCD

AT HADRON COLLIDERS

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Quantum Chromodynamics (QCD) is the theory which describes the strong interactions between quarks and gluons [1]. We will review some QCD-related results from the Tevatron, located at Fermilab in Batavia, IL, USA. The Tevatron is a proton antiproton collider with an energy in the center of mass of almost 2 TeV, which makes it the highest energetic collider in the world before the advent of the Large Hadron Collider (LHC).

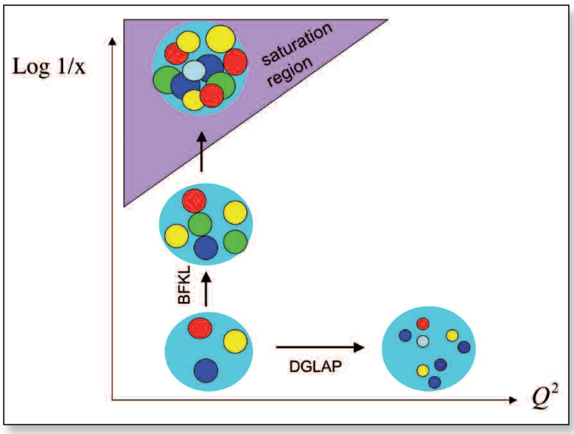
▲ The Fermilab accelerator complex accelerates protons and antiprotons close to the speed of light. The Tevatron, four miles in circumference, is the world's most powerful accelerator, producing collisions at the energy of 2 tera electron volts (TeV). In a tiny volume, these collisions recreate the conditions of the early universe. Two experiments, CDF and DZero, record the particles emerging from billions of collisions per second.

The LHC is a proton proton (pp) collider with a center-of-mass energy of 14 TeV which produced its first collisions last year. We will first describe how the proton structure in quarks and gluons can be constrained using Tevatron data, and what can be expected at the LHC. Next, we will describe surprising events called exclusive diffractive events which will have important consequences at the LHC and especially for future physics projects in ATLAS and CMS, two main experiments at the LHC [1].

QCD studies at Tevatron and LHC

The principle of QCD studies and their interests are given in Figure 1. Protons can be considered as made of quarks and gluons. The proton structure is more complicated than the familiar structure in valence quarks *uud* (up-up-down). In most of the kinematical domain reached at Tevatron or at LHC, the proton constituents are the valence quarks, the sea quarks (pairs of quark-antiquarks) and the gluons. The two variables which characterize the interaction are x, the fraction of the proton momentum carried by the quark which interacts, and Q^2, the square of the energy transferred between both protons. Small x-values correspond to high quark/gluon density, each quark/gluon carrying a small fraction of the proton momentum. Q^2 acts like the resolution power of a microscope. When Q^2 gets larger, one sees a larger domain inside the proton, and the size of the quark/gluon is smaller. The LHC will allow probing scales in the proton which were never reached before, by accessing values of x down to 5×10^{-7} and Q^2 up to 10^8 GeV^2. For comparison, the Tevatron only reaches Q^2 up to 2×10^5 GeV^2.

Two evolution equations can describe the proton evolution in Q^2 and x, respectively: the Dokshitzer Gribov Lipatov Altarelli Parisi (DGLAP) equation in Q^2 and the Balitski Fadin Kuraev Lipatov (BFKL) equation in x. Once the quark and gluon distributions are known for a given value Q_0^2, it is possible to use the DGLAP equation to know them at any Q^2 value, and to compare the results to the measurements performed at Tevatron, for example. We will describe some examples of such measurements that are fundamental to understand further the structure of the proton. It is also possible to predict the evolution in x using the BFKL equation. For a given Q^2, one looks at the proton for a given value of the microscope resolution, *i.e.*, for a given area inside the proton. When x decreases, the number of gluons increases. At some point, the number is so large that they start overlapping each other, and one can no longer neglect the interactions between the different gluons. This is the saturation domain. One of the challenges for the LHC is to see this new domain where the standard evolution equations do not hold.



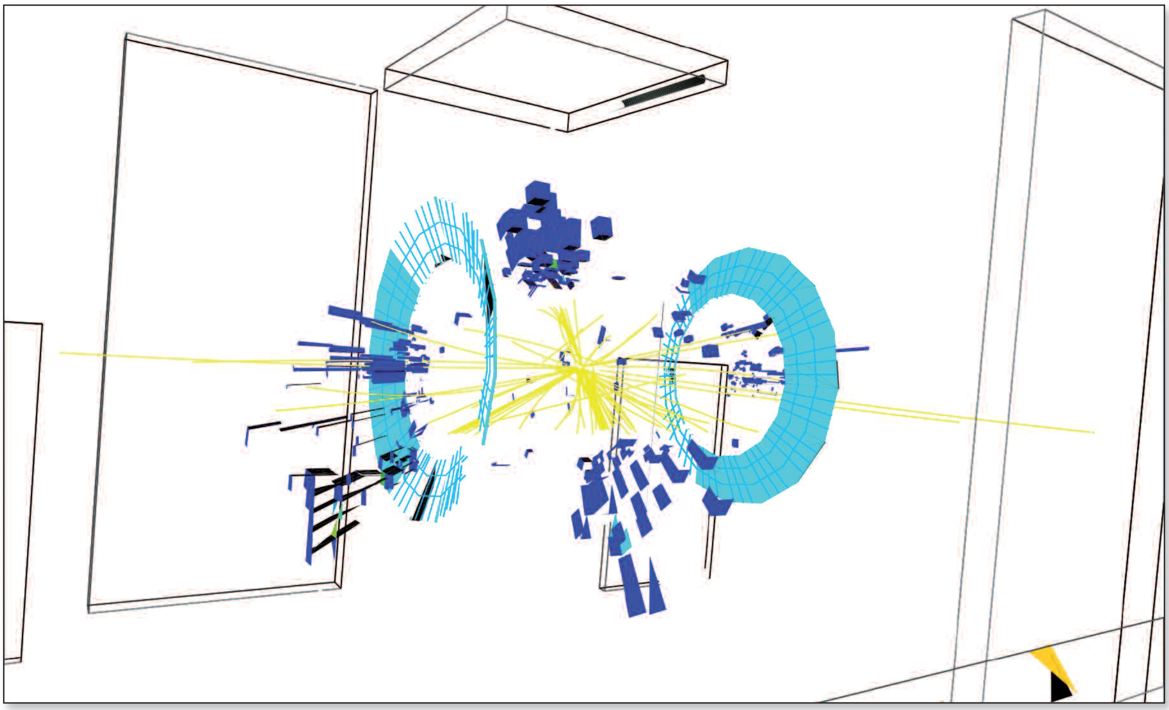
► **FIG. 1:** QCD at hadronic colliders. Here x is the fraction of the proton momentum carried by the quark which interacts, and Q^2, the square of the energy transferred between both protons (see text).

Constraints of quark and gluon structure

The first measurement sensitive to the proton structure performed in the two experiments at the Tevatron (called D0 and CDF) is the inclusive jet cross section. The event showing the highest jet transverse momentum is shown in Figure 2. We see that there are two 'jets', bunches of particles originating from the hadronization of quark and gluons in dark blue in the lower and upper part of the detector. The protons were completely destroyed and the available energy of about 2 TeV was spread in the two jets and the dark blue proton remnants are seen on the right and left sides of the detector. The transverse momentum of each jet is of the order of 600 GeV, and the dijet mass of 1.2 TeV, which makes it one of the highest mass objects ever produced in particle accelerators.

This kind of events is sensitive to beyond-Standard-Model effects such as quark substructure and allows constraining directly the structure of the proton in quarks and gluons since the rate of jet production is directly related to it. Calibrating precisely the jet energy (with a precision of about 1%) using the energy balance in very clean events, where only one photon and one jet are present, is quite a complicated and challenging task but is fundamental to get a precise measurement of the jet cross section. Data are compared to DGLAP calculations and a good agreement is found over six orders of magnitude as shown in Figure 3 [2].

Let us mention that many other measurements such as dijet mass, multijet cross sections, jet shape, W and Z boson inclusive production cross sections can also further constrain the proton structure.



► **FIG. 2:** Event with the highest transverse momentum jets (in dark blue - D0 experiment)

How do the uncertainties on the proton structure affect the LHC potential?

Another question is whether the uncertainty in the proton structure and also of the QCD calculation can affect the LHC discovery potential. As an example, the cross sections for Higgs boson production are known precisely both for background and signal (typical uncertainties: 5 to 15%). However, to perform QCD calculations, perturbative developments in series of strong coupling constant are done which leads to additional uncertainties of about 9%.

On the other hand, the LHC discovery potential (supersymmetry, Higgs boson, extra dimensions) can be affected if the background is poorly known because of the uncertainties on the proton structure. As an example, we can quote the effect of new interactions and extra dimensions, which might be of the same order as the present gluon and quark density uncertainties for some values of the parameters.

Mueller-Navelet jets

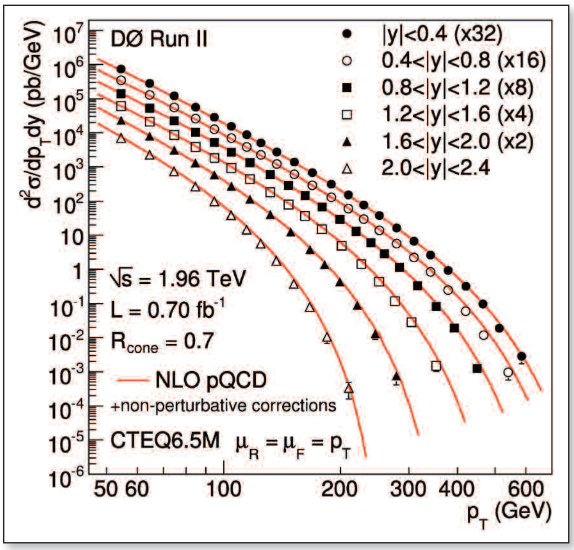
Mueller-Navelet jets are jets produced in *pp* collisions, requiring these two jets to be as far away as possible in polar angle, and to have about the same transverse energy. The DGLAP evolution equation ensures that the gluons emitted between these two jets are ordered in transverse energy. Since the two jets have about the same values of transverse energy, the probability that gluons can be emitted following the DGLAP equation is very small. On the contrary: the BFKL prediction is expected to be higher. Another easier observable is the measurement of the difference in azimuthal angle $\Delta\varphi$ between the two forward jets. Since there are few gluons emitted for the DGLAP evolution, $\Delta\varphi$ is peaked towards π whereas the BFKL expectation will lead to a flatter distribution. This measurement will be performed at Tevatron and LHC and can be a test of BFKL resummation effects as well as saturation phenomena [3].

Interest of exclusive events

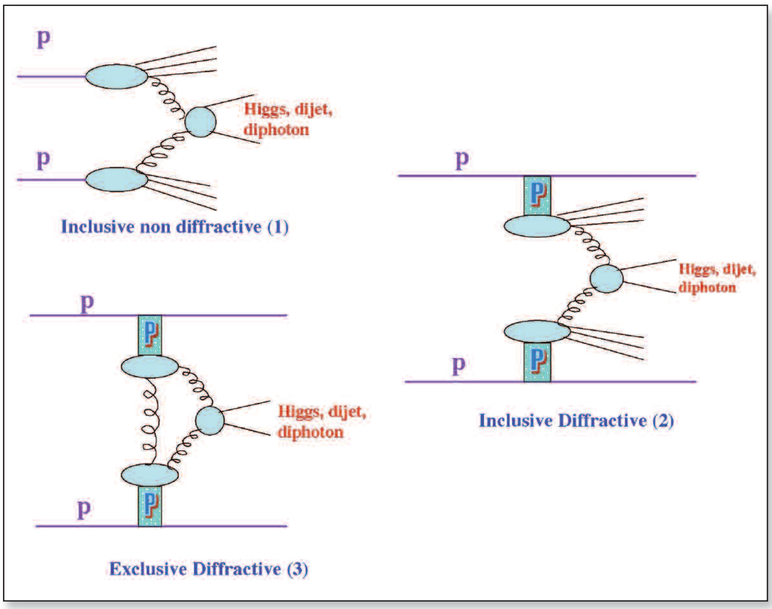
Before discussing exclusive events, let us introduce diffractive events. In most events, the proton is completely destroyed after the interaction and we observe only part of the proton remnants directly in the detector. In about 1% of the events at Tevatron, the situation is completely different: no energy above noise level is deposited in the direction of the proton or antiproton. This can be explained if the proton stays intact after the interaction. These events are called "diffractive".

A schematic view of non-diffractive, inclusive and exclusive diffractive events at Tevatron or LHC is displayed in Figure 4. The upper left plot (1) shows the "standard" non diffractive events where the Higgs boson, the dijet or diphotons are produced directly by a coupling to the proton and shows proton remnants. The right plot (2) displays the standard diffractive exchange where the protons remain intact after interaction and the total available energy is used to produce the heavy object (Higgs boson, dijets, diphotons...) and the remnants. The third class of processes is displayed in the bottom left figure (3), namely the exclusive diffractive production. In this kind of events, the full energy is used to produce the heavy object and no energy is lost. It means that for this kind of events all particles produced in the final state can be detected, for instance the final state protons and the Higgs boson [4].

There is an important consequence for the diffractive exclusive events: the kinematical properties, such as the mass of the produced object or its spin can be computed very precisely using the information on the intact protons. As an example, the mass of the Higgs boson if produced in this way can be computed with an accuracy of 2 to 3% [4].



◄ **FIG. 3:** Jet cross section as a function of jet transverse momentum in six bins corresponding to different jet angles.



▼ **FIG. 4:** Scheme of non diffractive, inclusive and exclusive diffractive events at the Tevatron or the LHC

Exclusive events at Tevatron

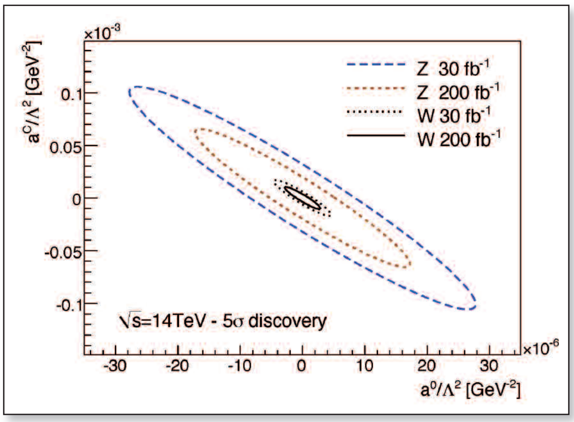
The CDF collaboration searched for exclusive events in many different channels and especially measured the so-called dijet mass fraction in dijet events – the ratio of the mass carried by the two jets produced in the event divided by the total mass – when both protons are intact in the final state [5]. The diffractive exclusive events appear when the dijet mass fraction is close to 1 (we recall that in exclusive events, only two jets are produced and nothing else). Adding exclusive events to the distribution of the dijet mass fraction leads to a good description of CDF data [6].

Exclusive Higgs production

One special interest of diffractive events at the LHC is related to the existence of exclusive events and the search for Higgs bosons at low mass in the diffractive mode especially in the supersymmetric scenario, an extension of the Standard Model in particle physics. Many studies were performed recently [4,7,8] to study in detail the signal over background for supersymmetric Higgs boson production in particular, and most of the supersymmetric parameter space can be covered using the first years of data taking at LHC.

Photon-induced processes

Photon-induced processes at LHC, and especially *WW* boson production [9,10], are especially interesting. The cross sections of these processes are computed with high precision using Quantum Electrodynamics (QED) calculations, and an experimental observation leading to differences with expectations would be a signal due to beyond-Standard-Model effects. The experimental signature of such processes is the decay products of the W boson in the main ATLAS or CMS detectors (two main experiments at LHC) and the presence of the intact scattered protons in the final state.
New physics beyond the Standard Model can manifest itself as a modification or appearance of W or Z boson couplings such as the triple $WW\gamma$, $ZZ\gamma$, or quartic $WW\gamma\gamma$, $ZZ\gamma\gamma$ couplings. It is worth noticing that many observed events are expected at high energy where beyond-Standard-Model effects are expected. The present sensitivity on quartic couplings can be improved by almost four orders of magnitude at LHC using the full luminosity as shown in Figure 5 [9], and it will be possible to test the Higgsless or extra dimension theories where these couplings appear naturally.



► **FIG. 5:** Discovery potential on new quartic $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings using the data at the LHC [9].

Future Detectors at LHC

To perform the potential studies described above, the ATLAS and CMS collaborations have the project to install forward detectors at 220-240 and 420 m allowing to measure precisely the position and arrival time of the intact protons in the final state. Timing detectors are also especially interesting for medical applications since they would allow improving the present resolution of the PET imaging detectors by one order of magnitude. ■

About the author

Christophe Royon is Research Director at the Service de Physique des Particules, Institut de Recherche Fondamentale sur l'Univers du Commisariat a l'Energie Atomique in Saclay France. He is member of the D0 collaboration at the Tevatron, Fermilab, Chicago USA and the ATLAS collaboration, CERN, Geneva, Switzerland. He performed his PhD in the H1 experiment at HERA on the first measurement of the proton structure function at low x. He was convener of the muon, QCD, and jet energy scale groups in the D0 experiment and is now the convener of the calorimeter group in the D0 experiment and the co-coordinator of the ATLAS Forward Physics project with Prof. Brian Cox and Prof. Stephen Watts of the University of Manchester.

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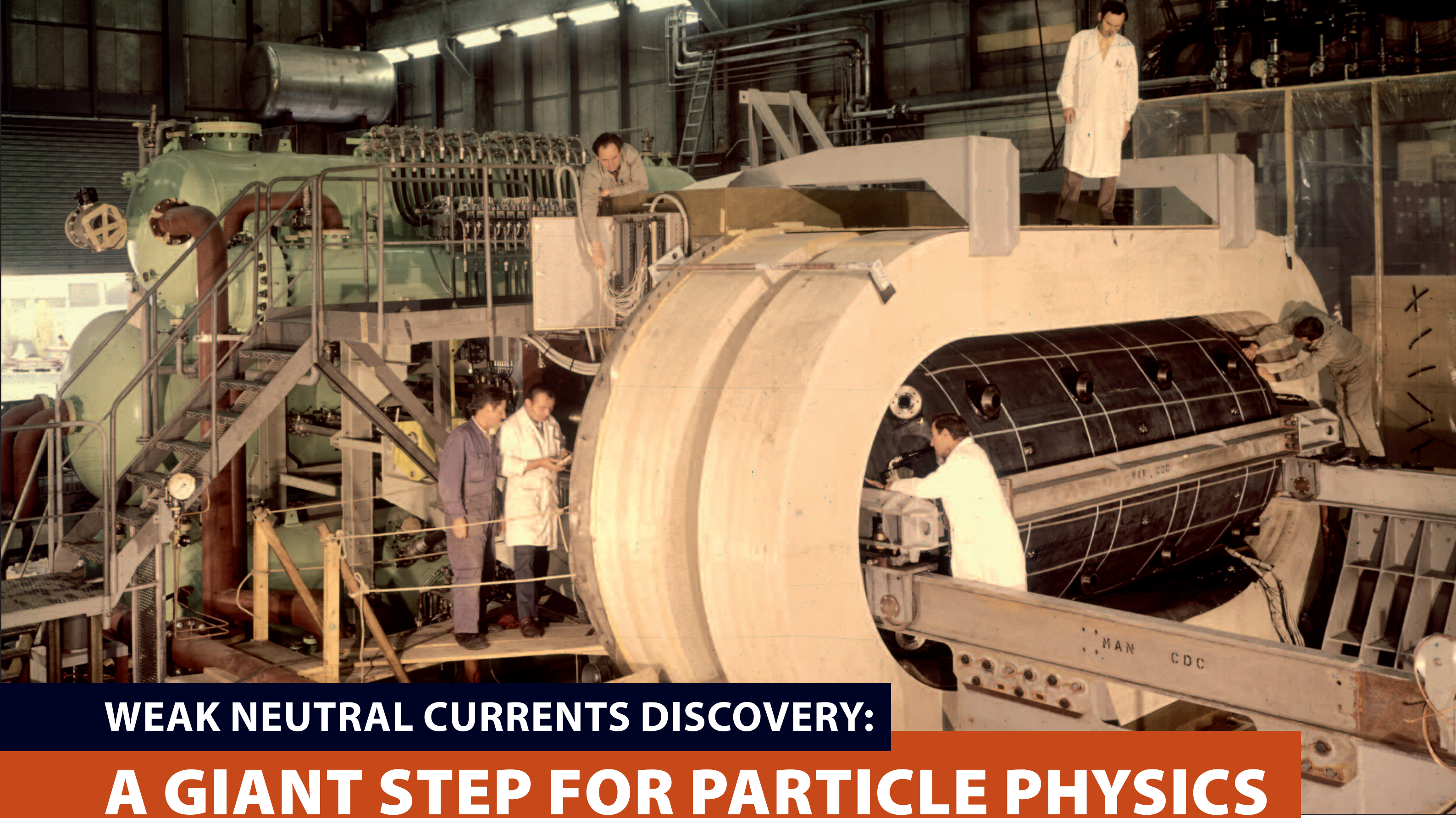

WEAK NEUTRAL CURRENTS DISCOVERY: A GIANT STEP FOR PARTICLE PHYSICS

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Subatomic particles interact with different kinds of forces (strong, electromagnetic, weak and gravitational). In case of the weak force, the interaction is due to the exchange of intermediate charged ($W^{+,-}$) and neutral (Z^0) bosons. These cases are referred to as "charged currents" and "neutral currents", respectively. When evidence for such 'Weak neutral currents' was first published in 1973 the high energy physics community was incredulous.

▲ the whole Gargamelle setup © CERN

It took the community a year to acknowledge the discovery. But this discovery, perhaps the most important made at CERN, was the onset of a new era in our understanding of fundamental interactions. Thirty-six years after the discovery, the 2009 EPS Prize for High Energy and Particle Physics was awarded to the Gargamelle[1] Collaboration for the observation of the weak neutral current interaction [1,2]. The award ceremony took place at the EPS-HEP 2009 Conference [3] in Krakow (Poland). The story of the discovery shows how difficult sometimes it can be to drastically change widespread beliefs.

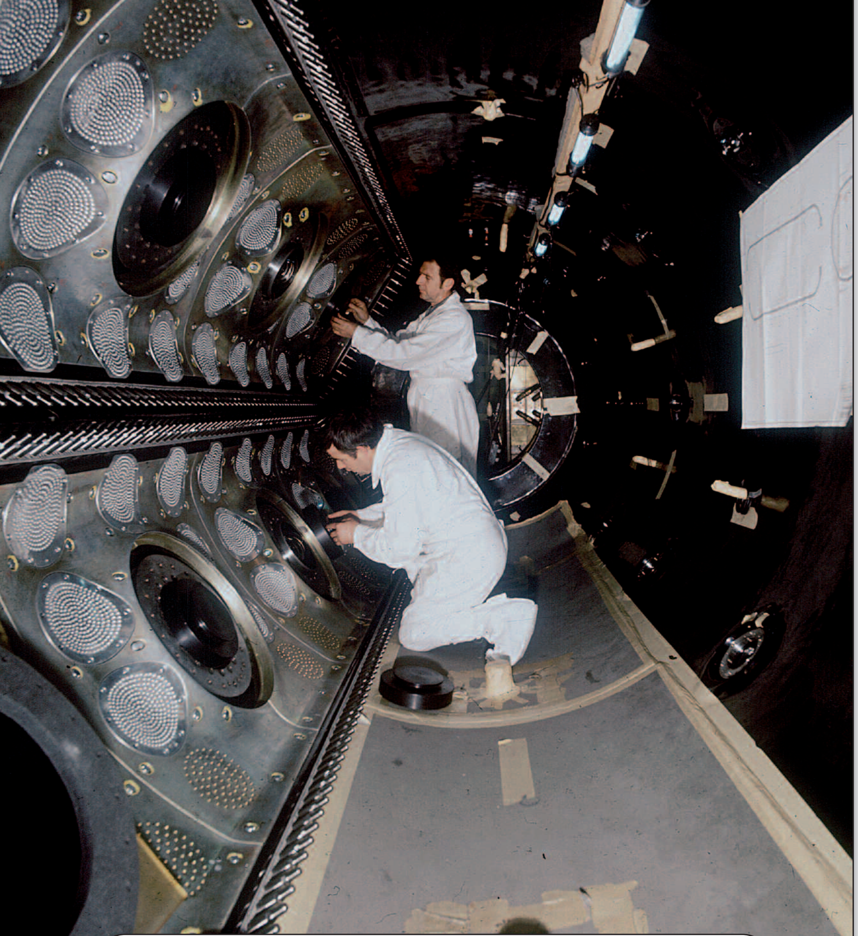
Elementary particles and their interactions, now and before

All phenomena observed so far in Nature are understood as manifestations of the 'elementary world'. In our current understanding the microscopic world is made of 2 families of so-called "elementary" particles (6 leptons and 6 quarks) interacting via 4 fundamental interactions: the strong, electromagnetic, weak and gravitational forces. In today's theory, the so-called Standard Model (SM), the first three interactions are described by the exchange of spin-1 gauge bosons: strong interactions are mediated by gluons, electromagnetic interactions by photons, weak interactions by charged charged ($W^{+,-}$) and neutral (Z^0) massive vector bosons. Gravitational interactions are still not well understood at the microscopic level but there is a general belief that the mediator is the graviton (a spin-2 particle).

In the late 60's, only the electromagnetic interaction mediated by the photon was really well understood and described by the Quantum ElectroDynamic theory (QED). Weak interactions were understood in terms of the so-called Fermi theory, proposed in 1934 by Enrico Fermi [4] and modified in the late 50's to account for parity violation. This theory was a local theory, in the sense that the weak interaction was not mediated by exchange of a vector boson which propagates: it was a

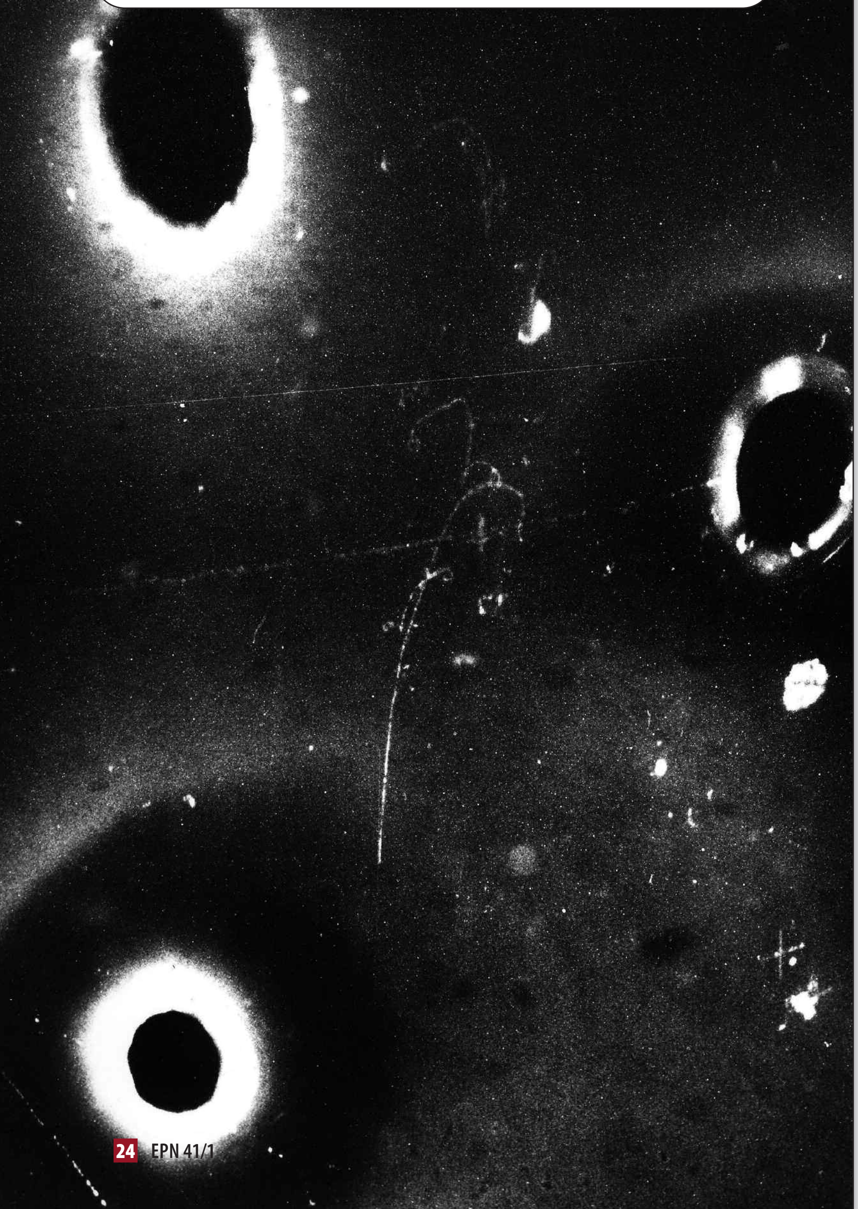
note

[1] Gargamelle was chosen as the name for the giant bubble chamber, after the giant mother of Gargantua in novels by François Rabelais (16th century).



▲ **FIG. 1:** Gargamelle heavy liquid bubble chamber. Inside view.

▼ **FIG. 2:** Leptonic Neutral current interaction. First event ever found.



point-like interaction. Low-energy processes, such as neutron beta-decay (in which a neutron decays into a proton, an electron and an antineutrino), or muon decay (in which a muon decays into an electron, a muon-like neutrino, and an electron-like antineutrino) were quite well described by this theory. However, everybody knew that this theory could not work at high energy since it has divergences (prediction of infinite cross-sections at high energy).

The Standard Model introduced by A. Salam, S.L. Glashow and S.Weinberg in 1967 [5] allowed to overcome this problem, and even more, to propose a unified theory of weak and electromagnetic interactions. But it needed the existence of the weak neutral current interaction.

In weak interaction processes observed at that time, a charged lepton was always associated with a neutral lepton (hence a "charged current"). Strange particles were also known, and their observed decay had the same property. There were on the contrary very strong experimental bounds on decay modes such as for the K^+ meson into a charged pion, a neutrino and an antineutrino (with a pair of neutral leptons, hence the name "strangeness-changing weak neutral current"). As a consequence, at the beginning of the sixties there was a widespread belief that neutral current interactions, with strength comparable to the charged current ones, could not exist.

The birth of the Gargamelle project

For a precise and detailed study of weak interactions, the neutrino is an ideal probe since it is not sensitive to any other kind of interaction. The project to build a giant heavy liquid bubble chamber to study in-depth neutrino interactions, and thus weak interactions, was born at the Sienna conference in 1963 from a discussion between Profs. André Lagarrigue and Luis Alvarez. The driving ideas were i) a huge target mass for statistics ii) a long enough path in the liquid to detect and identify all particles going out of the primary interaction vertex and their secondaries. The projected bubble chamber was called Gargamelle, from the name of the giant mother of Gargantua in novels by François Rabelais (16^{th} century). After an agreement in 1965 between the CEA-Saclay for building the chamber, and CERN to operate it in a neutrino beam, the Gargamelle collaboration was formed in 1967 by seven laboratories: Aachen, Brussels, CERN, Paris, Milano, Orsay and London. Gargamelle was designed and built under the leadership of André Lagarrigue, and assembled and operated at CERN (fig. 1) by a team including Paul Musset and André Rousset. But in the White report written by the collaboration to establish a shopping list of reactions to study, the neutral currents had only the 10^{th} priority!

Exciting news for weak interactions theories

In the late 60's and early 70's, some important theoretical developments boosted the interest in the search for weak neutral currents. The Glashow-Weinberg-Salam theory of electroweak interactions among leptons predicted the existence of a massive neutral weak boson [5]. The Glashow-Iliopoulos-Maiani (G.I.M.) mechanism was explaining, via the introduction of a hypothetical heavier fourth quark (charm, in addition to up, down and strange), the suppression of strangeness-changing neutral currents, while permitting strangeness-conserving ones [6]. The proof of renormalizability (to avoid divergences) for such theories by 't Hooft and Veltman [7] in 1971 led particle physicists to take the G.I.M. predictions more seriously and revived the interest of the Gargamelle collaboration for neutral currents. Furthermore new calculations about semileptonic Weak Neutral Currents [8,9,10] were published.

Neutral currents hunting is opened

In a collaboration meeting in March 1972 the Milano group showed the first hints of neutral currents in neutrino interactions with at least one pion outgoing. It was immediately decided to put the highest priority on the search for neutral currents among the million pictures to be taken with the Gargamelle detector and its 12 cubic meters of liquid heavy Freon CF_3Br in the neutrino/antineutrino beam at CERN. The chamber was ideally suited for this search due to its very high particle identification capability. Since the beam at CERN consisted mainly of muon-like neutrinos and antineutrinos, neutral currents could manifest themselves in muon-neutrino elastic scattering off electrons (purely leptonic neutral current), or neutrino scattering off nuclei of liquid freon without prompt muon or electron in the final state (semi-leptonic neutral current).

The first beautiful, but not yet conclusive, hint of such interactions was an event observed in Aachen around Christmas 1972, an isolated electron compatible with the interpretation of muon-neutrino elastic scattering off electrons (fig. 2).

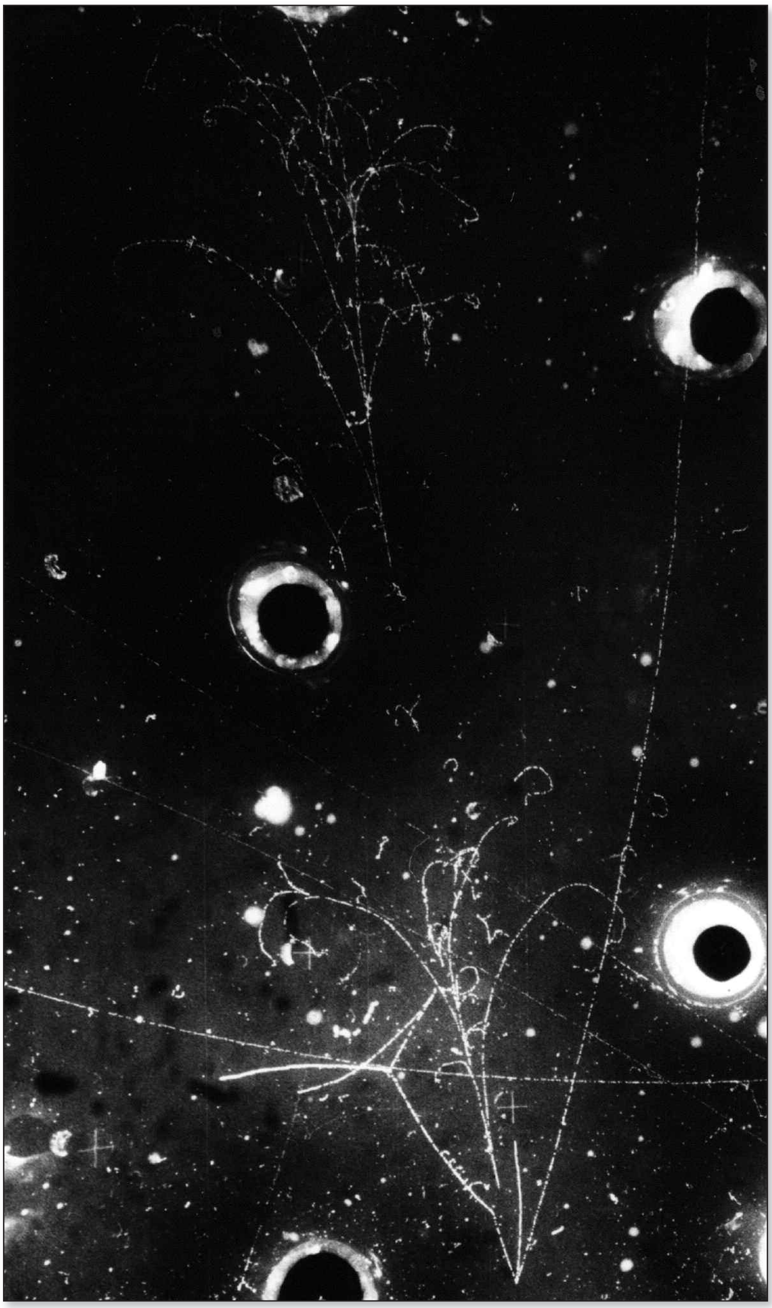
The semi-leptonic neutral current interaction (so-called hadronic events) had a much higher probability to occur. However, they could be simulated by background reactions, mainly interactions in the liquid of high-energy neutrons produced in neutrino interactions out of the visible volume (fig. 3 a charged current event, and fig. 4 a neutral current event). The collaboration worked hard to get reliable and safe estimates of this background using simulations, calculations based on equilibrium arguments, and an evaluation of the apparent interaction length of the events. A direct measurement of the neutron's behaviour in the chamber by an exposure of Gargamelle to a proton beam was also performed.

Eventually, the collaboration was convinced that the result was solid and reliable.

After a seminar by Paul Musset at CERN in July '73, the first evidence for both leptonic and semi-leptonic neutral currents was published by the collaboration in the same issue of Physics Letters in September 73 [1, 2]. 55 physicists, from groups at Aachen, Brussels, CERN, Paris, Milano, Orsay and London signed the discovery.

Epilog

The high energy physics community reacted incredulously to the announcement of the discovery. Around the same time a neutrino experiment in Fermilab (HPWF) claimed that they do not see neutral currents.



▼ **FIG. 3:** A charged-current event. The track on the right leaves the chamber without any interaction, identifying it as a muon with high probability.

So, for months people thought that the result was dubious. Fortunately, in early '74, two new leptonic neutral current candidate events were found in Gargamelle films, reinforcing the confidence of the collaboration in their result. Eventually, the Fermilab experiment, after modifying their apparatus, confirmed in summer '74 the result of Gargamelle [11] and another experiment (CITF) showed an irrefutable evidence of the existence of Neutral Currents [12].

Soon after the discovery of Neutral Currents, the fourth quark predicted by the GIM mechanism was discovered simultaneously at BNL [13] and at SLAC [14] in the USA. The electroweak theory was quickly recognized, and Nobel prizes were awarded to Glashow, Salam and Weinberg in 1979, for their theoretical work. Gargamelle was left in the shadow, very likely due to the sudden death of André Lagarrigue in early '75. In 1983, the intermediate weak bosons W^+,W^- and Z^0 were discovered at CERN, putting a final touch to the story. Many experimental measurements have now been performed, on a large field of physics phenomena, and the continuing agreement with the Standard Theory has been used to put more and more stringent bounds on possible new physics beyond the Standard Theory. Thirty-six years after its discovery, the weak neutral current interaction remains the most recent fundamental interaction to have been unambiguously observed. Thanks to the European Physical Society, this exciting endeavor has been revived. ■

▼ FIG. 4: A so-called "semi-leptonic neutral current". All the tracks interact in the liquid, signifying that there is no muon, and so no charged lepton outgoing.

Authors biography

Jean-Pierre Vialle, Laboratory of Annecy-le-Vieux of Particle Physics (LAPP), Université de Savoie and CNRS/IN2P3. After Gargamelle, he worked on the UA1 experiment at CERN and signed the discovery of the intermediate weak bosons W+/W- and Z0. Since 1996, he is working on astroparticle physics. Now he is head of the AMS space experiment project in France.

Antonino Pullia, Physics Department of the University of Milano-Bicocca and I.N.F.N. Section. Antonino Pullia is Full Professor in Physics since 1976; he has held teaching positions at Bari, Milano and now in Milano-Bicocca Universities; he was Director of the Physics Department of Milano-Bicocca during 2003-2005; since 2006 he is Director of the corresponding I.N.F.N. Section. He was awarded the prize "Luigi Tartufari" of the Accademia Nazionale dei Lincei for Physics in 2008.

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COSMIC RAYS

AND GLOBAL WARMING

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Is global warming man made or is it caused by the effects of solar activity on cosmic rays as claimed by some? Here we describe our search for evidence to distinguish between these claims.

The year 2009 marks the 50th anniversary of the paper by Ney [1] drawing attention to possible effects of cosmic rays on clouds. With Global Warming a well known fact, some have followed up this possibility, sometimes with great publicity [2]. Their argument is that the observed increasing solar activity during the last century caused a decrease in the ionization due to cosmic rays since the lower-energy cosmic particles are deflected by the magnetic field created by the increased solar wind. This would lead to a decrease in cloud cover, if there is a connection, allowing more heating of the Earth by the sun. Hence they propose that such a natural phenomenon, rather than man-made greenhouse gases causes the warming. Meteorologists on the International Panel on Climate Change IPCC [3] have put forward strong reasons that man-made greenhouse gases are most likely responsible for global warming. However, there is still an outside chance, which has been estimated to have probability of about 10%, that there is some other cause. In this case the models used by the meteorologists to calculate the effects of the increased greenhouse gases would need to be wrong. In addition, there has to be some, as yet, undiscovered mechanism which would cause the unusually rapid global warming seen over the half last century. Could the undiscovered mechanism be the proposed effect of cosmic rays on cloud formation?
Positive evidence for an effect of cosmic rays on clouds was first presented by Friis-Christensen and Svensmark and later by Marsh and Svensmark and Palle-Bago and Butler [4] using newly available satellite data on clouds [5]. They noticed that as the sun went through the maximum activity in its 11 year cycle in 1990 the new data on the globally averaged low-level cloud cover showed a decrease (see figure 1a). Using this observation they proposed that ionization from cosmic rays was a big contributor to cloud formation and the changing solar activity was responsible for the observed global warming via cosmic rays. Several papers followed pointing out possible flaws in the argument. One flaw was that other measures of cloud cover did not show the same structures as those shown in figure 1a.

▲ The 'man-made global warming-denier' will have to look elsewhere: cosmic ray-driven clouds will not do the job.

Notwithstanding this, since the effect would be so important and far reaching, a group of us got together to try to find evidence to corroborate or otherwise the hypothesis that changing cosmic ray activity has something to do with either cloud cover or global warming.

The solar cycle peaking in 2000

Another solar cycle has passed since the one which produced the dip in low level cloud cover in 1990 shown in figure 1a. Figure 1b shows the data sample up to 2008 covering both solar cycles. The dip in low cloud cover seen in 1990 is clearly visible. During the following solar cycle from 1996-2007 the low-level cloud cover decreases rather smoothly and this is observed to be matched by an equivalent increase in cloud cover at higher altitude. However, there is no clear dip at the next solar maximum in 2000. Hence the following solar cycle does not provide corroborative evidence of the connection between changing cosmic rays and changing cloud cover, at least on a global scale.

▲ Radioactive 'events' and their influence on cloud cover: Tchernobyl, April 26, 1986. Very considerable amounts of fall-out. No increase in cloud cover: η(conversion ions to cloud droplets) < 3%

A clever statistical analysis by Voiculescu et al [6] showed that there were local geographical regions of strong correlation between cloud cover both with the cosmic ray rate and with solar irradiance variation. We examined these regions using both completed solar cycles of data. We found that both solar cycles gave visible structures in the cloud cover for the high correlation regions with solar irradiance. However, both solar cycles were not clearly visible for those with cosmic rays. Hence any effect of solar activity on clouds and the climate is likely to be through solar irradiance rather than cosmic rays. We could not find any geographical characteristics which would explain such behaviour for these regions, however. Nevertheless since solar irradiance transfers 8 orders of magnitude more energy to the atmosphere than cosmic rays it is more plausible that this can produce a real effect. Indeed, such an effect has been modelled [7].

Chernobyl, bombs and radon

Another place to look for corroborative evidence for ionization playing a part in cloud formation is to examine whether ions from other sources give rise to clouds. We have searched for excesses of cloud cover associated with the Chernobyl disaster in 1986, fall out from nuclear bomb tests (specifically the 15 MT BRAVO test of 1954) and natural radon emissions over India [8]. In no case could a change in clouds, caused by changing ionization, be identified. The upper limits to the efficiency for converting ions to cloud droplets being, respectively, 3%, 0.01% and 25%; a value of nearly 50% would be needed to explain the dip in low-level cloud cover seen in Figure 1a. In addition, we examined times of changing cosmic radiation, the so called Forbush decreases and ground level events [9]. Again, no statistically significant change in cloud cover during such events could be identified. However, in a recent paper [10], the Svensmark group reports evidence that the water content in clouds decreases at a time of about 7 days after selected large Forbush decreases. It is difficult to envisage how such a time delay can occur given that the lifetime of ions in the atmosphere is thought to be much shorter than 7 days [11].

There are unknown climatic effects surrounding all of these tests. So no doubt a good lawyer would think of reasons why such analyses are not appropriate for the cosmic ray case. However, we can conclude that these tests do not provide corroborative evidence of the proposed link between ionization and cloud formation.

Cosmic rays over the Earth

Figure 1 represents the results for cloud cover averaged over the Globe. However, both the cosmic ray intensity variation and that of clouds varies over the Earth's surface, the former for reasons of the geomagnetic field and the latter for meteorological reasons. Thus, Figure 1 is a gross over-simplification.

We have examined the equivalent of Figure 1 from place to place over the Earth's surface [9]. The cloud cover variation is identified by the dip, the difference between the low-level cloud cover (LCC) for 1990 and the adjacent maxima. The cosmic ray intensity variation (over the 11-year cycle) is characterised by the 'vertical rigidity cut-off', VRCO (see, *e.g.*, [12]). High VRCO-values occur near the Equator, where the geomagnetic field is nearly orthogonal to the cosmic ray arrival directions. Here, the cosmic ray intensity and its variation is low since low energy particles are deflected and prevented from entering the atmosphere. Low VRCO-values are to be found near the Poles where low energy particles can enter the Earth's atmosphere along the field lines. In consequence the amplitude of their 11-year cycle is much bigger.

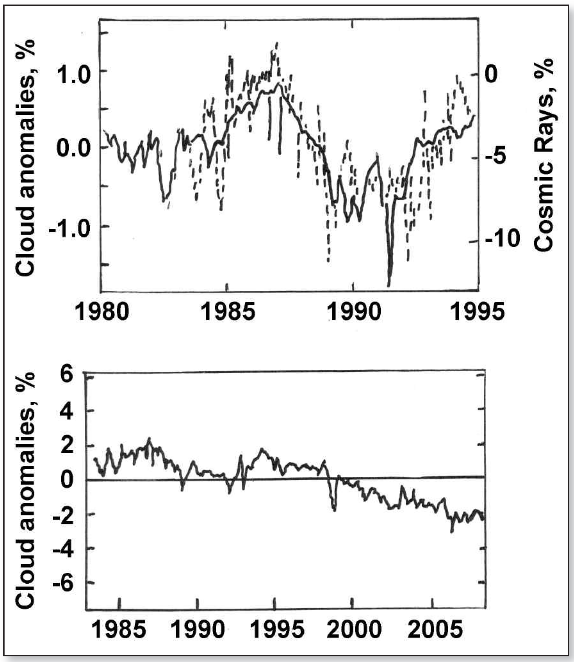
Figure 2 shows the situation. The data are divided into latitude bands, as indicated. The (very useful) variation of

VRCO with longitude along a particular latitude bin arises because of the obliquity of the Earth's magnetic dipole. The result is that going along a particular geographic latitude, the meteorological conditions should vary less and a correlation of dip with VRCO will be more meaningful. 'Expectation', the observed fractional cosmic ray variation in Figure 2, is marked as NM. It is evident that the magnitudes of the dip depths are independent of VRCO, *i.e.*, that variations in cloud cover do not follow variations in cosmic rays intensity. Hence this evidence fails to corroborate the connection between cosmic rays and clouds.

We went on to show that, when averaged over the 11 year solar cycle, there was a common oscillation of four quantities: the global mean surface temperature of the Earth, the cosmic ray ionization rate in the atmosphere, the mean daily sun spot number and the solar irradiance [13]. This showed a period of roughly twice that of the 11 year solar cycle. The temperature, solar irradiance and sun spot number were observed to be in phase whereas the cosmic ray flux lagged behind by 2-4 years. Hence the temperature variation is unlikely to be caused by the cosmic ray variation. The amplitude of the observed oscillating temperature variation was ±0.07°C. Let us assume that this oscillating temperature is caused by either the solar irradiance oscillation or, despite our arguments, that from cosmic rays. The overall long-term variation of both the solar irradiance and the cosmic rays was much less than the amplitude of the oscillation for each. It follows that the total global warming must be less than the amplitude of the temperature oscillation of 0.07 degrees. This is 14% of the observed 0.5 degrees. Hence the total contribution of variable solar activity to global warming must be less than 14% of the total temperature rise.

Cosmic Ray effects in the Upper Atmosphere

It is clear that if there is going to be a cosmic ray effect anywhere it should be at high altitude. The reason is that the cosmic ray ionization rate increases strongly with altitude - the phenomenon observed by Viktor Hess which led to his deduction, in 1912, that the radiation responsible for the observed ionization was cosmic. We have searched for the correlation of cloud cover with altitude for the 3 height bands into which the cloud cover is divided: low cloud cover (LCC) below 3.2 km, middle cloud cover (MCC) for the range 3.2 to 6.5 km and high cloud cover (HCC) above 6.5km. Figure 3 shows the results [14], presented as a function of latitude. The upper plot shows the absolute amounts of the cloud cover in the 3 altitude bands. The middle plot shows the correlation coefficients between the cosmic ray rates and the cloud cover from each altitude band. The lower plot shows the correlation coefficient between the LCC and MCC and a

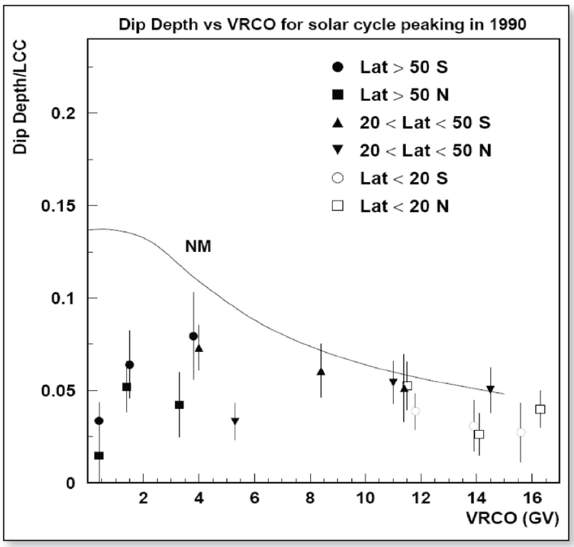


◄ **FIG. 1:** **a)** Upper plot shows the ISCCP D2 IR data on the low cloud cover anomalies (dashed curve) and the cosmic ray intensity (solid curve) as measure by the Huancayo neutron monitor for the solar cycle 1986-95. 'Anomalies' are cloud cover deviations from the average corrected for seasonal variations. **b)** Lower plot shows the same anomalies from 1983-2008 covering the two solar cycles.

quantity to measure the sensitivity of one to the other. The latter plot is an indicator that some of the correlations are due to the vertical transference of clouds from one region to another.

It is seen that the correlation with the cosmic ray rate is largely negative for the high altitude clouds, MCC and HCC, opposite to expectation if there were a causal link between cosmic rays and clouds. This is yet another reason why we should discount the effect of cosmic rays on the cloud cover, at least by way of their direct effect on cloud formation. This proviso is put in because there is just a small chance that, following [15], there may be an effect of cosmic rays on the upper atmosphere, which affects its transparency and thereby surface temperatures.

These effects seem to demonstrate that there could be a small effect of solar variability on clouds. However, as we showed above, the effects are more likely to be

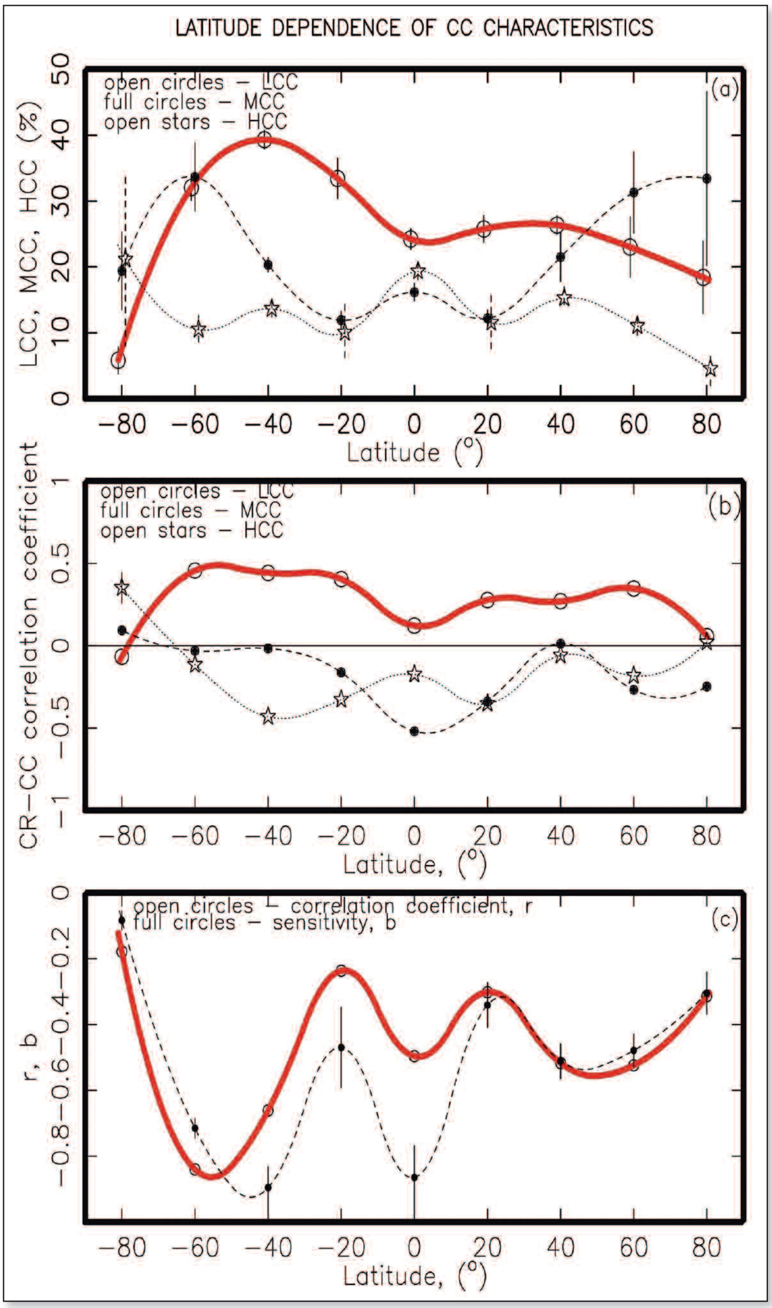


◄ **FIG. 2:** The observed modulation of the low-level cloud cover (LCC) as measured from the fit to solar cycle peaking in 1990 data from Figure 1a. On the horizontal axis is the 'Vertical Rigidity Cut-Off' (see text). The `modulations' are expressed by the dip amplitude (maximum to minimum) at the time of the solar maximum in 1990 divided by the mean LCC. The smooth curve labeled NM shows the expected fractional modulation of the rate of cosmic ray ionization at low-level cloud height.

something to do with changes in solar irradiance - given the much greater energy input from this source - than from cosmic rays.

Conclusions

In our view the jury is back and the verdict is that cosmic rays and solar irradiance are not guilty for most of the Global Warming. Nevertheless, they could be responsible for a contribution and we look forward to future experiments such as CLOUD at CERN which should be able to quantify to what extent ionization plays a part in the production of aerosols, the precursors of cloud formation. ■



▲ **FIG. 3: The latitude dependence of Low-, Medium- and High-Cloud Cover characteristics (a) absolute values of LCC, MCC and HCC; (b) correlations with cosmic ray intensity (Climax neutron monitor); (c) the correlation coefficient (red) and sensitivity (black dashed curve) of MCC to LCC, from [12].**

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PHYSICS IN DAILY LIFE: BUBBLES AND BALLOONS

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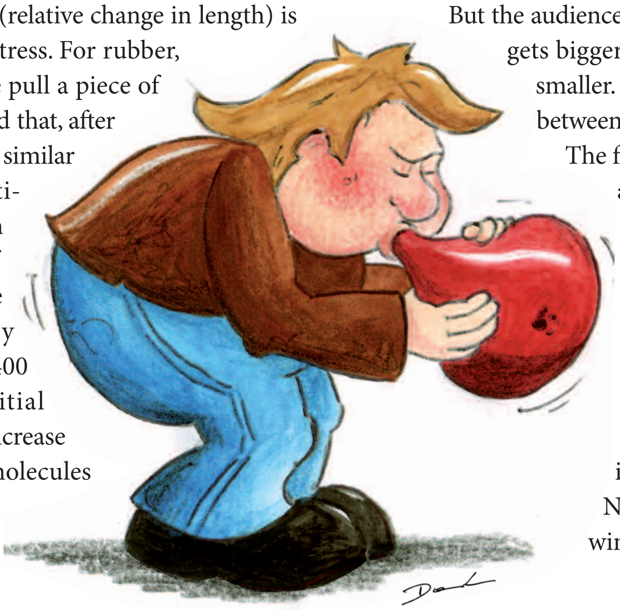
When blowing soap bubbles as kids, we were probably much too fascinated by their beautiful colours to realize that there is some interesting physics going on. For one thing, the very existence of the bubbles demonstrates the concept of surface tension, since the slight overpressure inside the bubble has to be balanced by attractive forces in its 'skin'. And, in the process, it teaches us that, for a given volume, a sphere has the smallest surface area.

Blowing up a rubber balloon reveals some additional interesting aspects. Since the forces involved are much larger, some are easily noticed. We have all experienced that the first stage of blowing up a balloon is the hardest. Once the balloon has reached a certain volume, things get easier. The pressure needed decreases. This is funny, because everyone knows that, if you stretch a piece of rubber, the force required *increases* with length.

To fully understand the behaviour of the balloon, we need to know a bit more about the elasticity of rubber. This turns out to be significantly different to the normal behaviour of a common elastic material, for which Hooke's law holds: strain (relative change in length) is proportional to applied stress. For rubber, things are different. If we pull a piece of rubber band apart, we find that, after an initial rise in the stress similar to Hooke, there is a relatively flat plateau which ranges from strains of about 50 % to 200 %. Here the stress is reasonably constant. Only at about 400 % – four times the initial length – does the stress increase steeply, since the macromolecules making up the rubber become fully stretched.



Now back to the balloon. Remembering the 'plateau' we assume for argument's sake that the 'surface tension' τ (force per unit length) is constant, just like in the case of soap bubbles. If we now consider a spherical balloon to consist of two imaginary halves and write down the force balance between the two halves ($\pi R^2 p = 2\pi R\tau$, with p the overpressure in the balloon), we find that the pressure needed to keep the balloon inflated is inversely proportional to the radius R. This qualitatively explains the fact that blowing-up the balloon gets easier once it has reached a certain size.

This observation calls for a spectacular experiment to amuse your audience. Take two balloons, inflate one of them to roughly one third of its maximum size and the other to two thirds. Attach both balloons to a piece of tubing while keeping the connection between the two closed with your finger. Ask the audience what will happen if you let go and connect both balloons through the tube. Sure enough, the audience expects the balloons to become equally big. After all, this is what happens if you take the two connected *un*inflated balloons and pull them apart: they will both be stretched to the same size. But the audience is wrong. The big balloon gets bigger and the smaller one gets smaller. It illustrates the difference between force and pressure.

The funny properties of rubber are also at the heart of the remarkable behaviour which we see if we inflate a long, sausage-shaped balloon. We find that two 'phases' coexist at a single pressure. But here the physics is a bit more complicated. Not quite as simple as blowing bubbles. ■

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