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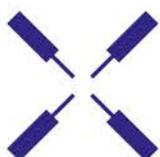
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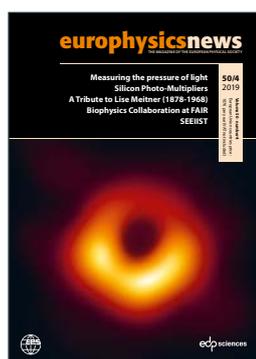


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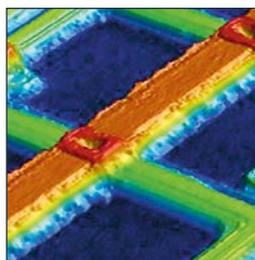


# euromphysicsnews

**Cover picture:** © Event Horizon Telescope collaboration.

The Event Horizon Telescope Collaboration will receive the prestigious 2020 Breakthrough Prize in Fundamental Physics "For the first image of a supermassive black hole, taken by means of an Earth-sized alliance of telescopes."

The \$3 million prize will be split equally among all coauthors of the first six papers published by the EHT on April 10, 2019 which can be found at [https://iopscience.iop.org/journal/2041-8205/page/Focus\\_on\\_EHT](https://iopscience.iop.org/journal/2041-8205/page/Focus_on_EHT)



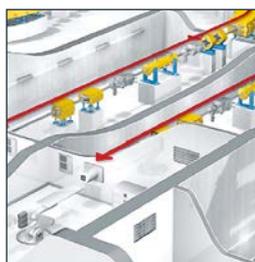
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[EDITORIAL]

## Building ITER – more than just a modern-day Cathedral?

The EPS Executive Committee was fortunate to be able to hold its meeting on 6<sup>th</sup>/7<sup>th</sup> June 2019 at the ITER fusion science and technology research facility at Cadarache, France. In addition to meeting the Director General, Bernard Bigot, we had a tour of the site to see progress with ITER's construction.

**M**ake no mistake, this is an extremely challenging project and one whose 7 Members (China, EU, India, Korea, Japan, Russia and USA) represent 50% of the world's population and about 85% of its global GDP. A global effort, then, to demonstrate that fusion can be a viable and sustainable future energy source, one that is a net generator of energy. This is critical, as amongst the large tokamaks that went into operation in the 1980s, JET in Europe and the American TFTR may both have achieved Deuterium-Tritium Fusion, but both machines required more energy to "light the fire" than the fire had given in return. ITER aims for a return of 10:1; that is 500MW output from 50MW heating input. It also aims to demonstrate that the fusion reaction can be stable and sustained for much longer periods than in current machines. How will it manage this when other machines have not?

As Bernard Bigot explained, in this case size matters. ITER will contain more than 10 times the volume of plasma of JET (830m<sup>3</sup> vs 80m<sup>3</sup>). The magnetic cage, that will shape and confine the hot plasma in its vacuum vessel, uses 10,000 tons of superconducting magnets with heights up to 17m and 24m in diameter and a combined stored magnetic energy of 51 Gigajoules. Housed in a 30m × 30m cryostat, the overall weight of the machine is some 23,000 tons. The project is entering a critical phase as components arrive on site and are prepared and preassembled before being integrated into the machine. Many of the components are too big to be transported complete to Cadarache

and so we were able to see coils of superconducting cable being wound for the magnets and the cryostat being welded together. It is this need to assemble such large components to geometric tolerances of a few mm that means the project is working at the leading edge of what is possible from an engineering perspective.

Another feature of many ambitious physics projects is the timescale necessary to achieve success. It was the 28<sup>th</sup> June 2005 when it was decided to build ITER in France and ground was broken for construction at Cadarache in 2007. The project is now just over 65% complete on its plan to achieve First Plasma in 2025. After that it will be another 10 years until Deuterium-Tritium Operation will commence. Many of the 2,300 workers, technicians and engineers currently involved in construction, will not still be active in the project when fusion is finally demonstrated at ITER. Nor many of the 3000 specialists from around the world who have been involved in the design and development of this unique research facility.

The high level of international collaboration has been both a key ingredient and a key challenge, necessitating integration of the in-kind contributions of components and materials provided by Members, whilst ensuring that their performance and quality achieve tight specifications. Bertrand Bigot emphasised the importance of adopting a strong "One ITER Team" project culture that puts the success of the project first, bringing together the ITER organisation, Domestic Agencies and suppliers to deliver on time and to required standards.

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**Cathedrals can stand for hundreds of years, whereas we hope ITER will have made its main contribution, and laid the foundations for the fusion machines and power plants of the future**

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As we toured the site, the thought struck us that building ITER had many similarities with building a Cathedral in Mediaeval times. Strong leadership was needed with the motivation to build something remarkable and, of course, the available funding to so do, raised from the people via tithes and taxes. Architects of the great Cathedrals broke new ground with innovations such as flying buttresses, vaulted ceilings and the construction of domes. Materials were transported from around the country, or further afield, to ensure highest quality. Construction began with the foundations, which was a specialist skill as faulty foundations could lead to weakness in the walls above ground, especially when the roof was added. Building took tens of years with teams of craftsmen and labourers employed. Many craftsmen involved in the beginning of construction did not live long enough to see the final result. Yet they were still committed to playing their part. Not every innovation worked in practice and many labourers lost their lives in pursuit of perfection. With the health and safety culture in place at ITER this is one area of similarity that should not arise! Cathedrals can stand for hundreds of years, whereas we hope ITER will have made its main contribution, and laid the foundations for the fusion machines and power plants of the future, when it achieves its demonstration of 500MW of energy output from its Deuterium-Tritium "burning plasma" in the late 2030s. ■

■ **Frances Saunders,**  
EPS Treasurer

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# IUPAP: towards its centenary and towards an IYBSD in 2022/2023

**The International Union of Pure and Applied Physics (IUPAP) was created in 1922 with the mission to assist in the worldwide development of physics, to foster international cooperation in physics, and to help in the application of physics toward solving problems of concern to humanity. To celebrate its centenary, IUPAP is pushing for an International Year of Basic Sciences for Development (IYBSD) 2022/2023. For this, IUPAP is seeking for support.**

IUPAP is an international non-governmental organization. Its guiding principles include:

- Foster openness and inclusiveness in physics;
- Ensure integrity and credibility;
- Promote physics as a building block of innovation and multi-disciplinary research;
- Promote physics as an essential tool for development and for sustainability;

IUPAP is organised in Working Groups for specific subjects and (affiliated) Commissions that o.a. sponsor major conferences in Physics, promote the guiding principles and award Young Scientific Prizes. It has strong relationships with neighbouring Unions. Currently, it is a leading partner in the LAAAMP (Light-sources for Africa, the Americas, Asia and Middle East Project) project 'Utilisation of Light Source and Crystallographic Sciences to Facilitate the Enhancement of Knowledge and Improve the Economic and Social Conditions in Targeted Regions of the World'. 'Gender Gap' is another example of a project in which IUPAP is involved. The aim of this project is to provide easy access to material proven to be useful in encouraging girls and young women to study science.

In 1922, IUPAP had only 13 Member Countries. This number has grown to 60 Members today (see the map) and we are actively seeking new members. Note, that not all countries in Europe with a strong physics community are members of IUPAP! Being a member of IUPAP means:

1. To be part of the "concert" of nations in Physics and so take part in the IUPAP General Assemblies and be part of the resolution making process.
2. To be part of the world physics community represented by IUPAP and thus enable scientists to cooperate freely across political boundaries.

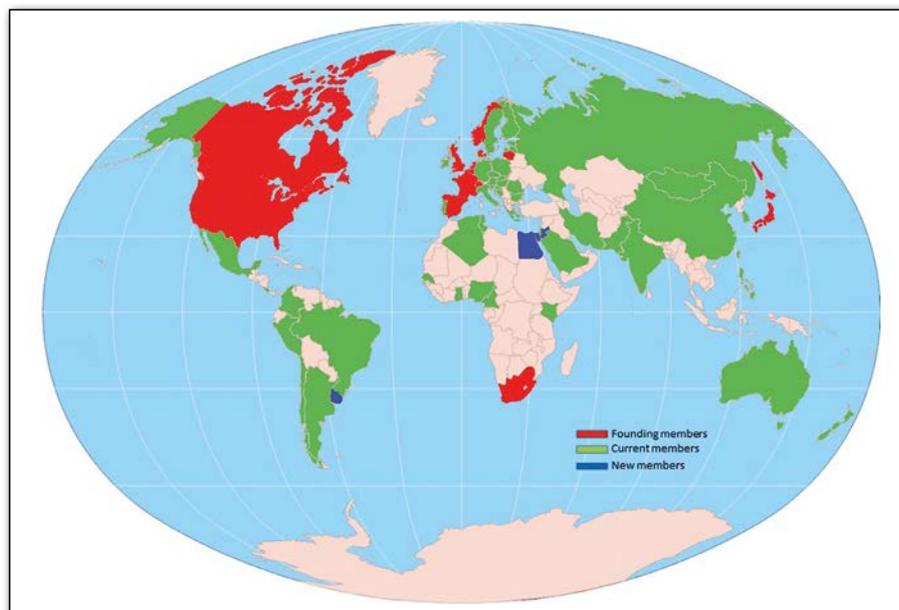
3. To have a fair representation in commissions and other physics endeavours of general interest for every country, namely physics for development, physics and industry, physics education, physics for society... To participate in working groups and committees that are relevant to addressing some specific challenge facing physics in the world.
4. To have links and networks with allied disciplines of physics through affiliated commissions and other allied international unions, and through IUPAP to be a part of ISC (the council of all scientific unions).
5. To have a chance to host some prestigious IUPAP conferences or events.
6. To receive the support of IUPAP for support of physics and science in their country or territory.

For IUPAP the benefit of more members is:

1. To consolidate its global footprint and strengthen its advocacy for scientific evidence-based decisions.
2. To better reach across national boundaries and ensure the free circulation of scientists through global physics cooperation in a world that is becoming more fragmented.
3. To better enable scientists to participate in decision-making that impacts physics on an international level in significant ways.
4. To create a more inclusive international platform where scientists can raise their voices and express their views on any matter that relates to physics and the practice of physics, and in so doing help to propose solutions and action plans to address such matters.

EPS (European Physical Society), APS (American Physical Society), AAPPS (Association of Asia Pacific Physics Societies) and the African Physical Society are observer members of Council and General Assembly of IUPAP. This is a place where they could meet together regularly.

To celebrate the centenary of its creation in 2022 and the centenary of its first General Assembly in Paris in 2023, IUPAP plans to organize big events in Geneva and in Paris which could be part of the events organized in the framework of a much wider project



▲ Map of IUPAP members

that IUPAP is pushing: an **International Year of Basic Sciences for Development in 2022/2023**.

The rationale for an **International Year of Basic Sciences for Development (IYBSD 2022/2023)** is very strong:

- Although it is generally recognized that science is useful for society, quite often, basic sciences are not considered as they should deserve, in the discussions concerning the societal, environmental and economic development.
- After the International Year of Physics, the International Year of Chemistry, the International Year of Mathematics, the International Year of Astronomy, it is time to plan an International Year of Basic Sciences for Development.
- **2022** would be a good time to celebrate **Basic Sciences for Development** (fits well with UNESCO and UN agenda, **IUPAP centenary, 100 years Niels Bohr Nobel award, Stern and Gerlach, Compton scattering, 200 years Brazil independence**).

Example of how much Basic Sciences contribute to development are given below:

- The WEB was born at CERN from the needs of global collaboration for fundamental science.
- The success of Google, the second largest company in the world, comes from a brilliant mathematical idea.
- Artificial intelligence relies on statistical

methods and will have an influence on all aspects of society.

- Cellular phones come from the discovery of transistors and WiFi astronomy spin-off developments.
- GPS accuracy is a spin-off of Einstein General Relativity, and the improvement in accuracy of atomic clocks based on quantum technology.
- The discovery of DNA has revolutionized Medicine.
- The Genome Project has opened the way to gene therapies.
- The development of innovative instrumentation for Basic Sciences has many impacts for Health and Development: PET, MRI, Adaptive Optics.
- The rapid uptake of the generation and storage of renewable energy depends on advances in physics, chemistry and materials science.
- Reduction in pollution and green chemistry relies on basic advances in chemistry
- ...

Tentative list of topics which could be covered are:

- Basic Sciences and Multicultural Dialogue.
- Basic Sciences, Education and Human Development.
- Basic Sciences and Women (figures, empowering women, role models).
- Basic Sciences, Innovation and Economy.
- Basic Sciences and Life Sciences.
- Basic Sciences and Global Challenges.

- Basic Science as a Global Public Good.
- Basic Sciences and the sustainable development goals.

Some possible resulting actions are:

- Institutionalize full implementation of open access publishing for all research papers connected to Fundamental Research, *i.e.* curiosity driven. This will allow free access to Universities to all published material in Basic Sciences.
- More generally promote Open Science in all Basic Sciences.
- Promote inclusive collaboration in Fundamental Research (teams from developed countries together with teams from developing countries, gender balance...)
- Organize top level international scientific conferences in developing countries with many side events. International Scientific Unions should be mobilized for that purpose.
- Promote training and education to Basic Sciences in developing countries.

The proposal of 2022 as the International Year of Basic Sciences for Development was well received and got the oral and then formal support of the representatives of ICSU (International Council for Science), ISSC (International Social Sciences Council), now ISC, IUPAC (International Union for Pure and Applied Chemistry), IAU, IMU, IUBS, ICTP (Abdus Salam International Center for Theoretical Physics), EPS (European Physical Society), CERN (European Organization for Particle Physics), JINR (Joint Institute for Nuclear Research), IRD (*Institut de Recherche et Développement*). The proposal was presented to the Jordanian, Palestinian, Russian, Nigerian and Vietnamese ambassadors to UNESCO and received a firm support to bring this project for approval by UNESCO. It was also discussed with the director at UNESCO, of Science Policy and Capacity Building, Executive Secretary of IBSP (International Basic Sciences Program at UNESCO), very supportive of the initiative. IBSP is giving its support.

The main steps are now:

- 2018 Formal recommendation by IBSP for 2022 – International Year for Basic Sciences for development
- 2019 Formal approval by the General Conference of UNESCO (November)
- 2020 Approval by the UN General Assembly (December)
- 2021 Detailed Preparation of Regional and International events
- 2022 International Year of Basic Sciences for Development

Your help is welcome to convince your delegations at UNESCO to promote the project and to participate to the project. ■

■ **Michel Spiro**

CEA and CNRS Emeritus

Research Director,

IUPAP President Designate,

Chair of the Steering Committee

for IYBSD

## UPGRADE OF CMS IS IN FULL SWING

The upgrade of the CMS detector at CERN is in full swing and provides nice pictures of people working on impressive technology.

Since January 2019, the LHC accelerator at CERN is shut down for two years for maintenance and upgrade. Of course, the LHC Collaborations use the shutdown to upgrade their detectors. In the picture you see two people working on the installation of muon chambers in the CMS detector. The CMS Collaboration is installing 144 additional muon detector modules for the detection of particles in the forward direction. The newly developed Gas Electron Multiplier (GEM) detectors will detect muons that scatter at an angle of about 10 degrees with the direction of the beam axis. Like in all gaseous ionisation detectors, in GEM detectors ionising particles passing through create electron avalanches in an electric field to produce a current or charge large enough to be detected by the electronics. In the case of a GEM detector, the avalanches are created in small holes in a metal-cladded



polymer foil. The foils are lithographically pierced with many small holes such that the voltage placed across the metal cladding creates a large electric field in each hole. A single electron passing through a hole creates an avalanche of electrons in the hole. The electrons exit the GEM at the back. To further enhance the electron

multiplication, in CMS a stack of three GEMs are placed after each other. ■

**Read more in** <https://home.cern/news/news/experiments/cms-tightens-its-net-around-muons>

© Image credit: Maximilien Brice, CERN

# EPS Statistical and Nonlinear Physics Prize 2019

## Awarded to Sergio Ciliberto and Satya Majumdar

The EPS Statistical and Nonlinear Physics Division organized its 2<sup>nd</sup> conference at Nordita in Stockholm in May 2019. One of the highlights was the award of the EPS Statistical and Nonlinear Physics Prize to two very distinguished physicists: Sergio Ciliberto (ENS Lyon) and Satya Majumdar (Paris-Sud (Orsay)). The conference dealt with the latest developments in the area of nonequilibrium statistical physics, stochastic modelling, complex networks, complex systems, nonlinear physics, and attracted quite a lot of famous speakers in the field, as well as many young people at the beginning of their career.

Where can be a better place to award a prestigious prize for major research achievements than the city of Stockholm? Sure, the EPS Statistical and Nonlinear Physics Prize is not the Nobel Prize, but it has gained considerable prestige in the statistical and nonlinear physics community in the two years since it was created by EPS in 2017. It is awarded every 2 years, for world-leading and agenda-setting contributions in the area of statistical and nonlinear physics, complex systems and complex networks. This year, the prize was awarded to Sergio Ciliberto and Satya Majumdar, both very distinguished scientists in the area of statistical and nonlinear physics. The award ceremony took place during the conference “Statistical Physics of Complex Systems” organized by the EPS Statistical and Nonlinear Physics Division at Nordita, the Nordic Institute for Theoretical Physics, in Stockholm, gathering some of the most distinguished speakers in this general area from around the world. The prize is traditionally shared by two outstanding physicists (if one can already say ‘traditionally’ for something that exists only for two years).

**Sergio Ciliberto** was honored “for his seminal contributions over a wide range of problems in statistical and nonlinear physics, in particular for performing groundbreaking new experiments testing Fluctuation Theorems for injected power, dissipated heat, and entropy production rates, as well as

*investigating experimentally the connection between dissipated heat and the Landauer bound, thus demonstrating a link between information theory and thermodynamics.”*

Sergio studied physics in Florence and was a researcher at the Istituto Nazionale di Ottica in Florence 1982-1990. He also spent some time as a postdoctoral researcher and visiting scientist in Orsay, at the University of Pennsylvania (Haverford College), and at the Center of Nonlinear Studies at Los Alamos National Laboratory. In 1991 he was appointed at the Laboratoire de Physique at ENS Lyon, being the Director of the Lab from 2000-2006. Part of his research was supported by a large ERC grant with the title “Out of equilibrium fluctuations in confined phase transitions”. From 2012-2014 he was Vice President of ENS Lyon in charge of research.

With Sergio Ciliberto the EPS honours an outstanding experimentalist whose work had a profound impact on several areas of statistical and nonlinear physics. Over his scientific career, he has explored many very different physical systems, and was able

to make very significant contributions over a wide range of problems. He has tested many innovative theoretical ideas in real physical situations, which led him to demonstrate the relevance of several deep concepts. He initially worked in quantum optics, then later he investigated order-chaos transitions in nonlinear systems, and worked in fluid turbulence, as well as on crack dynamics in heterogeneous materials and aging of amorphous materials. He then continued with his ground-breaking investigations on fluctuations of the injected and dissipated power in out-of-equilibrium systems. This was followed by his investigations of the connections between information theory and thermodynamics (experimental tests of the Landauer principle). Sergio Ciliberto also performed one of the first measurements of Liapunov exponents from an experimental time series, at a time when this topic was entirely new in the scientific community.

**Satya Majumdar** was honored “for his seminal contributions to non-equilibrium statistical physics, stochastic processes, and random matrix theory, in particular for his groundbreaking research on Abelian sandpiles, persistence statistics, force fluctuations in bead packs, large deviations of eigenvalues of random matrices, and applying the results to cold atoms and other physical systems.”

Satya got his PhD in Physics in 1992 from the Tata Institute of Fundamental Research in Bombay, India. He

▼ The EPS Statistical and Nonlinear Physics prize winners with their wives and the board members of the EPS Statistical and Nonlinear Physics Division. From left to right: Leticia Cugliandolo, Stefano Ruffo, Victoria Terziyan, Guido Caldarelli, Satya Majumdar, Christian Beck, Sergio Ciliberto, Margherita Ciliberto, Raul Toral, Paul Manneville.



then spent some time in the USA, first as a postdoctoral fellow at AT&T Bell Labs and then at Yale University. After briefly returning to Bombay, in 2000 he was appointed in Toulouse, France, to be followed in 2003 by his appointment as Directeur de Recherche at the University Paris-Sud, Orsay. Besides this, he also holds several honorary positions as an adjunct professor, at the Tata Institute in Bombay, at the Weizmann Institute in Rehovot, Israel, at the Higgs Centre of the University of Edinburgh, and at the Raman Research Institute in Bangalore, India.

Satya Majumdar is an outstanding theoretical physicist who made very significant contributions in many different subject areas of statistical physics, stochastic processes, and random matrix theory, with applications ranging from granular systems all the way to computer science and biology. His work is characterised by a very elegant mathematical analysis of physical problems, leading to a plethora of beautiful analytical results. These have provided deep insights into the underlying physics, but often also advance fundamental mathematical understanding. His work is probably almost as well known to probabilists and mathematical physicists as it is to statistical physicists. Some of his most important contributions are on self-organized criticality of sand-pile models, on stress propagation in granular systems, on persistence and first-passage properties in nonequilibrium systems, on sorting and search problems in computer science, and on extreme value statistics of correlated random variables. His seminal work in random matrix theory has applications for growth models, biological sequence matching, conductance distributions in quantum dots, and much more.

As said, the prize winners received their prizes in Stockholm during the EPS conference "Statistical Physics of Complex Systems", and were joined on this occasion by many other very well-known invited speakers of the conference. The complex network



community enjoyed the opening talks of leaders in the field such as A.-László Barabási and Ginestra Bianconi, for the fluctuation community there were Christopher Jarzynski and Gavin Crooks, the nonlinear dynamics community had the pleasure to listen to Leonid Bunimovich and Robert MacKay, and in total there was an impressive list of 28 invited speakers. But let us mention something else here that is equally important: the refreshingly large proportion of young PhD students and postdocs that attended the meeting, some of them being given the chance of presenting their results as a short oral contribution, others presenting posters.

Speaking about young outstanding researchers, the EPS Statistical and Nonlinear Physics Prize has an Early-Career analogue, which, similar as the senior prize, is also awarded every two years, again to two researchers that did outstanding contributions in the field, but with the condition of constraint that they are less than 6 years away from getting their PhD. This year this prize went to Karel Proesmans (Hasselt University) and Valentina Ros (ENS Paris), who both gave very inspiring Early-Career prize winner talks during the meeting.

A more applied perspective of the conference was delivered by a special symposium on "Statistical Physics of Power Grids", dealing with statistical physics methods for frequency fluctuations in power grids, renewable energy resources, demand control techniques, and similar topics, with the overall long-term aim to reduce the CO<sub>2</sub> emission. Many young people

▲ The entire conference went onto a boat trip for the conference dinner. The picture shows, from left to right, Michel Peyrard, Geneviève Peyrard, Claude Baesens, Robert MacKay.

from the physics community have recently started to work in this or related areas. It seems the conference symposium gave a good overview of what is currently done in this area by statistical physicists.

Thinking of possible social activities for a conference, what is a better place for a conference dinner than a boat trip? Indeed that was the idea, gather all 150 conference participants onto one (privately hired) boat and enjoy the beautiful view of the Archipelago, combined with a tasty Scandinavian buffet and a glass of wine or some other drink! It happened, and it was a great success. If you ever go to Stockholm, a similar trip is strongly recommended! The participants of the conference spent 4 hours together on the boat, enjoying the beautiful landscape floating by, and for sure some new research ideas in the general area connecting complex systems, statistical physics models, and nonlinear behaviour were created, re-created, discussed, modified, dismissed, or just put on hold until the next day. The local support staff from Nordita did a great job to make this boat trip happen. Overall this 2<sup>nd</sup> conference of the EPS Statistical and Nonlinear Physics Division was very stimulating and inspiring, not the least because it showed once again that techniques originally developed within the realm of statistical physics can be applied in a much broader context, to all kinds of scientific problems in various subject areas dealing with complex systems (defined as systems that are more than just the sum of their parts). Interdisciplinary research topics at the interface of the traditional boundaries of physics will continue to form a main focus of the EPS Statistical and Nonlinear Physics Division. ■

■ **Christian Beck**

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# Towards an update of the European Particle Physics Strategy

**The European Strategy for Particle Physics is the cornerstone of Europe's decision-making process for the long-term future of the field. Mandated by the CERN Council, it is formed through a broad consultation of the particle physics community around the world, and is developed in close coordination with similar processes in the US and Japan in order to optimise use of resources globally.**

**A**n update of the Strategy is currently under way, looking beyond the High Luminosity upgrade of the Large Hadron Collider (LHC) that was the highest priority of the last update in 2013. A major step in this process was the Open Symposium, attended by some 600 physicists, held in Granada, Spain from 13-16 May 2019.

Following the discovery of the Higgs boson in 2012, the measurement of the parameters of the Standard Model (SM) of particle physics with high precision is a major imperative. While the energy scale at which new physics may emerge is presently unknown, there is a general consensus that the search for possible deviations to the SM's predictions through a campaign of precise measurements is a reliable road towards breakthroughs in the field.

Determining precisely the properties of the Higgs boson, *e.g.*, how it couples to all the other particles of the Standard Model and to itself, and whether it couples to new (as yet unknown) particles, is a major objective of this strategy. With the High-Luminosity LHC (~2027-2037) many of the Higgs couplings will be measured with a precision of a few percent (typically 5-10 times better than today) but this may not suffice to probe the SM at the level required to reveal new phenomena.

An important debate at the Open Symposium was about the future colliders that could bring a substantial improvement in our understanding



of today's questions in particle physics.

Despite broad consensus on the central physics goals, the community is presently confronted with choices among potential future colliders. Although the HL-LHC will deliver protons and ions collisions up to the late 2030s, it is now the time to look beyond. Projected advances in accelerator technology, policy, time-scale and cost must be carefully considered. The merits and drawbacks of each collider option were discussed in great detail.

A new electron-positron collider at CERN, either circular (FCC-ee) or linear (CLIC), could lead to a further significant improvement, probing most of the Higgs couplings below the percent level. In combination with other precise electroweak observables at the Z pole and WW threshold, these measurements may lead the way towards answering some fundamental questions about our Universe, *e.g.*, the matter-antimatter asymmetry and the nature of dark matter. The determination of the shape of the Higgs potential is of particular importance as it is closely related to the electroweak phase transition. This information could be gathered by studying the self-interactions of the Higgs boson

at a high-energy hadron collider, such as FCC-hh, or the highest energy extension of CLIC. In Asia there are also plans for  $e+e-$  colliders with similar sensitivities to the colliders proposed at CERN.

Flavour physics and the physics of CP violation constitute an excellent indirect probe of new physics at scales much higher than those that can be directly reached by colliders. A variety of experiments will provide better measurements of flavour-changing B, D and K meson decays, and will search for electric dipole moments, for lepton flavour violation, and for flavour-changing Higgs decays. If deviations from the Standard Model are discovered, they will provide precious information on the scale of new physics and on the most promising routes to direct discovery.

It is worthwhile noting that the lack of appearance of new physics at the LHC or signs of weakly interacting massive particles as preferred candidates for dark matter is changing the paradigm about the properties of dark matter, opening the field to a broad range of masses spanning 80 orders of magnitude. With existing facilities, the low mass range can be probed either by looking for axions or axion-like particles from the cosmos or through production of dark sector messengers like dark photons in missing mass or beam dump experiments at accelerators.

For the energy frontier colliders, discussions on the reach in terms of physics beyond the Standard Model,

particularly dark matter, was also a major topic. It was highlighted that the FCC-hh would be sensitive to the mass range of weakly interacting dark matter particles.

Here again there are complementary approaches: upcoming upgrades to deep underground and satellite experiments will also improve the sensitivity to dark matter particles.

Advanced high-field RF systems are key to linear colliders. The International Linear Collider (ILC), proposed for construction in Japan, would use superconducting RF similar to that of the European XFEL project at DESY. The alternative Compact Linear Collider (CLIC) studied at CERN would use room-temperature RF structures with a two-beam acceleration scheme but could ultimately reach higher energy. On the other hand, the circular FCC-ee would require superconducting RF to achieve its target performance at several interesting energies, including the Z pole, the ZH cross-section peak, and the W-pair and top quark-pair thresholds.

High-energy hadron colliders beyond the LHC rely on longer tunnels and new, higher-field,

superconducting magnets. The most highly-developed contender is the Future Circular Collider (FCC-hh), built from 16 T magnets, in a 100 km tunnel attached to the present CERN complex. It could provide exploratory p-p collisions at 100 TeV collision energy with a reach for new physics scales as high as a few tens of TeV as well as a diverse programme of nuclear collisions to study high-density QCD. A comprehensive programme, spreading the cost and operation over decades, would start with the FCC-ee, an electron-positron collider in the same tunnel that could operate over the whole range of energies from the Z to the top-quark pair threshold.

Beyond these machines, novel acceleration schemes via beam- or laser-driven plasmas or colliding muon beams may eventually offer alternative paths to high energy collisions.

Despite impressive progress in recent years, it remains difficult to anticipate how and when these ideas could yield operational colliders with sufficient luminosity. The value of smaller facilities to demonstrate the new technologies was underlined.

Accelerator neutrino physics was already one of the main topics of the previous European Strategy program. Two major accelerator neutrino projects are in an advanced phase of approval and funding: DUNE in the United States and Hyper-Kamiokande in Japan. Their goals are to definitively measure CP violation in neutrino oscillations, a possible mechanism to understand the matter-antimatter asymmetry in the Universe, and to determine the neutrino mass ordering. CERN is contributing to these projects via the successful CERN Neutrino Platform. Non-accelerator future neutrino projects are JUNO in China and ORCA in Europe whose main goal is again the measurement of the neutrino mass ordering. Additional presentations regarded prospects for the measurements of the neutrino masses and the searches for sterile neutrinos and heavy neutral leptons.

The discovery of gravitational waves by Ligo/Virgo in 2015 was a major breakthrough in astrophysics. Europe is proposing an ambitious next generation interferometer, the Einstein Telescope, and the ways in which CERN could contribute to its definition were extensively discussed. A second breakthrough happened in 2017 with two events that marked the beginning of multi-messenger physics. The first one was initiated by gravitational waves (the neutron star-merging event GW170817) and the second was the first blazar associated with a high energy neutrino event (TXS 0506+056). This stimulated a discussion about new cosmic messengers and the possibilities of improving the sensitivity of the neutrino telescope IceCube in Antarctica, to complete the neutrino telescope KM3NeT in the Mediterranean Sea and to complete the CTA observatory for the detection of cosmic gamma rays.

Besides the large projects with their long time scales, it is important to maintain a degree of scientific diversity at CERN and other European laboratories. The initiative “Physics Beyond Colliders” at CERN aims at exploring the opportunities offered by the accelerator complex and infrastructure to address some of today’s outstanding questions in particle physics through experiments complementary to high-energy colliders. In particular, an SPS Beam Dump Facility covering a unique domain for hidden sector searches and a possible LHC fixed-target program dedicated to measurements of quark-gluon plasma properties and structure functions, could provide opportunities in domains uncovered by high-energy colliders and non-accelerator experiments.

The detailed presentations made at the Open Symposium can be reviewed at [https://indico.cern.ch/event/808335/timetable/#20190513\\_detailed](https://indico.cern.ch/event/808335/timetable/#20190513_detailed). ■

**High Energy and  
Particle Physics Division**

CERN Council Open Symposium on the Update of  
**European Strategy  
for Particle Physics**  
13-16 May 2019 - Granada, Spain




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# Highlights from European journals

## COMPLEX SYSTEMS

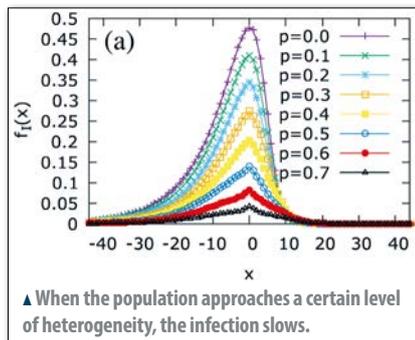
### How to stop diseases and forest fires from spreading

A new model, exploring how epidemics spread, could help prevent infections and forest fires from getting out of hand

Recently, epidemics like measles have been spreading due to the lack of vaccinations, and forest fires have become increasingly frequent due to climate change. Understanding how both these things spread, and how to stop them, is more important than ever. Now, the authors, have studied the way epidemics spread in heterogeneous populations. Their findings were recently published in EPJ B. ■

■ **A. B. Koltun** and **K. Laneri**,

'Rough infection fronts in a random medium', *Eur. Phys. J. B* **92**,126 (2019)



## APPLIED PHYSICS

### XXI International Conference on Ultrafast Phenomena 2018 (UP 2018)

The International Conference on Ultrafast Phenomena is the premier international forum for gathering the community of scientists and engineers in research and technology related to ultrafast phenomena covering the time scales ranging from picoseconds ( $1 \text{ ps} = 10^{-12} \text{ s}$ ) to attoseconds ( $1 \text{ as} = 10^{-18} \text{ s}$ ).

In the past decade, this field has moved ahead rapidly due to new laser- as well as accelerator-based sources of electron and light pulses, such as high harmonic generation, few-cycle optical pulses, sources of short wavelength radiation such as x-ray free electron lasers. Together with new methodologies, e.g. multidimensional spectroscopies, THz spectroscopy, electron-based techniques (EELS, PINEM, UED, etc.) and x-ray based techniques such as serial femtosecond coherent diffractive imaging, these great leaps forward are delivering an impressive



▲ Welcome laser beam from Elbphilharmonie to European XFEL.

degree of insight into phenomena both within atoms and between atoms and up in scale to macromolecular systems. These developments open up new perspectives for major applications in the fields of solar energy, molecular electronics, optoelectronic devices, biomimetic devices, etc... Last but not least, all this is accompanied by an improvement in theoretical models, which are indispensable for our understanding of phenomena on such ultra-short time scales. ■

■ **G. Cerullo, J. Ogilvie, F. Kärtner, M. Khalil** and **R. Li (Eds.)**,

'XXI International Conference on Ultrafast Phenomena 2018', *EPJ Web of Conferences* **205**, (2019)

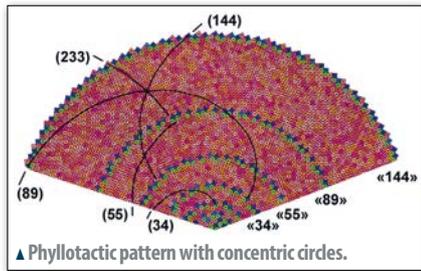
## BIOPHYSICS

### Collagen fibres grow like a sunflower

A new study suggests the pattern of fibres in tissues is similar to the petals of a flower

Collagen fibrils are a major component of the connective tissues found throughout the animal kingdom. The cable-like assemblies of long biological molecules combine to form tissues as varied as skin, corneas, tendons or bones. The development of these complex tissues is the subject of a variety of research efforts, focusing on the steps involved and the respective contributions of genetics and physical chemistry to their development. Now, the authors have shed new light on how complex collagen fibrils form. In a new study published recently, they focus on one of the hierarchical steps, in which molecules spontaneously associate in long and dense axisymmetric fibres, known as type I collagen fibrils. In this study, the spontaneous association step under scrutiny is

unique because the diameter of the fibre remains constant throughout its growth, while the end of growth manifests a characteristic parabolic profile. After studying several possible models, the researchers concluded the most likely explanation is that the fibres spread out from the fibre axis, along a stem, similar to how a sunflower's florets grow. ■



■ **J. Charvolin, and J-F. Sadoc,**

'Type I collagen fibrils: from growth morphology to local order', *Eur. Phys. J. E* **42**, 49 (2019)

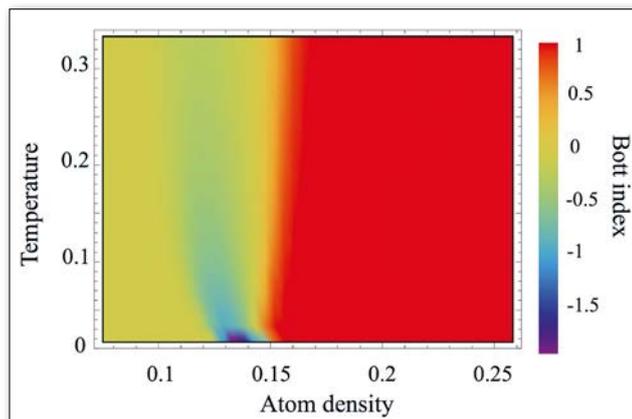
MATERIAL SCIENCE

## Topological Insulator in an Atomic Liquid particles

Topological insulators are a new class of materials whose electronic states are characterized by global topological invariants. Due to their nontrivial topology, these materials are able to conduct electricity on the surface despite being insulating in the bulk. Moreover, the metallic surface is robust against disorder and other imperfections, making topological insulators strong candidates for the building blocks of next-generation electronics technology. Although almost all known topological insulators are crystals, it has recently been shown that topological insulators and superconductors can also exist in the amorphous or glass states, as long as the relevant symmetries are maintained.

This work further generalizes the notion of topological materials by theoretically demonstrating an atomic liquid phase that supports topologically nontrivial electronic structure. Using quantum molecular dynamics simulations, it is shown

▼ Phase diagram of the model liquid system with topologically nontrivial electronic structure.



that by melting a topological crystalline state with elevated temperatures, the resultant liquid phase inherits the nontrivial topology that is characterized by a nonzero Bott index, named after the famous topologist Raoul Bott. This work points to a new systematic approach for searching topological phases in amorphous and liquid systems. ■

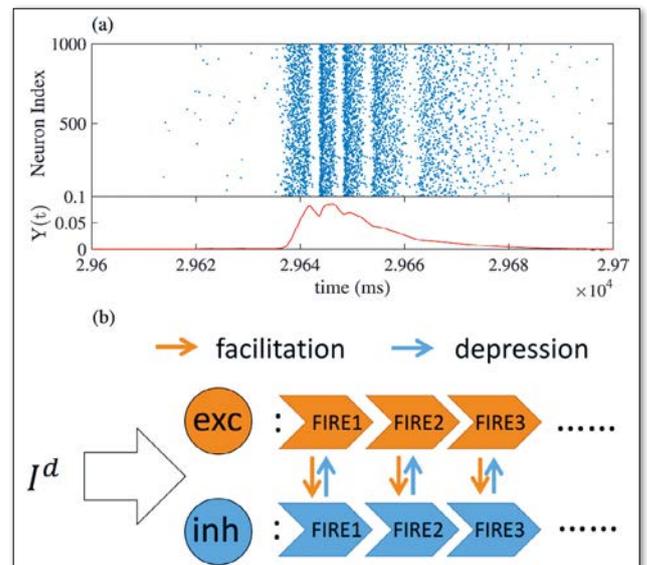
■ **G.-W. Chern,**

'Topological insulator in an atomic liquid', *EPL* **126**, 37002 (2019)

BIOPHYSICS

## Inhibitory neurons have two types of impact on brain oscillations

**A certain type of neuron, called inhibitory neurons, can have two types of overall effect on oscillations in the brain.**



▲ The emergence of synchronization with excitatory and inhibitory neurons.

Studying the brain involves measuring the activity of billions of individual brain cells called neurons. Consequently, many brain measurement techniques produce data that is averaged to reflect the activity of large populations of these neurons. If all of the neurons are behaving differently, this will average out. But, when the behaviour of individual neurons is synchronized, it produces clearly visible oscillations. Synchronisation is important to understanding how neurons behave, which is particularly relevant with regard to brain diseases like Alzheimer's, epilepsy and Parkinson's. Now, a group of researchers has used a combination of two computer models to study the ways different kinds of neurons can impact synchronisation. The study has been published recently. To study the effects on synchronisation, the authors examined neurons called inhibitory neurons – which work to slow down or stop the activity

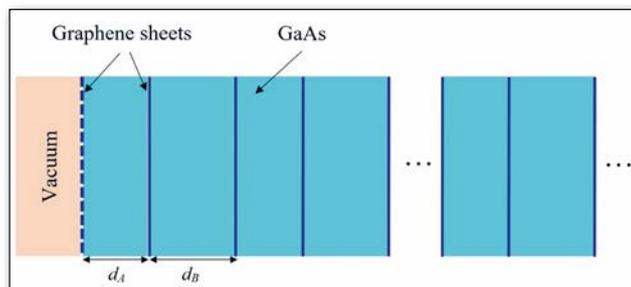
of other neurons. Moreover, they explored the likelihood of these inhibitory neurons firing either spontaneously or not at all within the network. ■

■ **P.-X. Lin, Ch.-Y. Wang and Z.-Xi Wu,**

'Two-fold effects of inhibitory neurons on the onset of synchronization in Izhikevich neuronal networks', *Eur. Phys. J. B* **92**, 113 (2019)

## MATERIAL SCIENCE

### Graphene plasmonics for semiconductor photonic crystals



▲ Side view of semi-infinite semiconductor photonic crystal.

The new area called graphene plasmonics is an emerging field that addresses the study and application of effects of the light interaction with the surface electron gas in the graphene sheet for the development of new devices. These types of light-matter interactions are called plasmon-polaritons. Specifically, surface polaritons are mixed excitations (where one of the components is the photon) that can propagate near the interface between two dielectric (or semiconductor) media; the associated electric and magnetic fields rapidly decay away from this interface. For this type of system, one of the most important basic questions with a view to device applications is to determine the polaritons' dispersion relation (or an equivalent energy-momentum diagram), which will be strongly dependent on the surroundings media. In a recent paper, the authors have studied a graphene system where they have a semi-infinite semiconductor photonic crystal with graphene sheets interlayers, whose external medium is typically vacuum (see the figure). They apply their results to doped GaAs and they have found that the graphene sheets play an important role in modifying the surface (and bulk) plasmon-polariton properties, mainly for the frequency region around 1 THz. ■

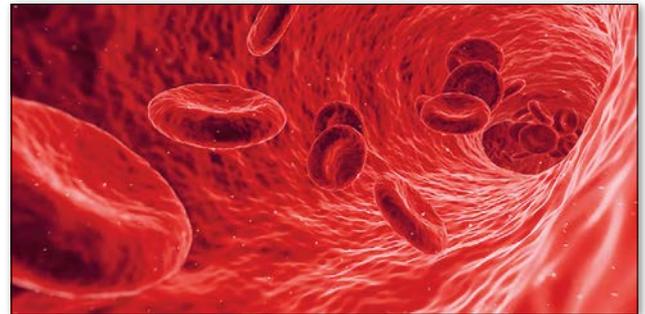
■ **M. S. Vasconcelos and M. G. Cottam,**

'Surface and bulk plasmon-polaritons in semiconductor photonic crystals with embedded graphene sheets', *J. Phys. D: Appl. Phys.* **52**, 285104 (2019)

## BIOPHYSICS

### How red blood cells behave in crowded vessels

**A new model, exploring how epidemics spread, could help prevent infections and forest fires from getting out of hand**



▲ Red blood cells flowing through a blood vessel

Blood consists of a suspension of cells and other components in plasma, including red blood cells, which give it its red colour. When blood flows through the narrowest vessels in the body, known as the capillaries, the interactions between the cells become much more important. In a new study published recently, a team of researchers has now developed a mathematical model of how red blood cells flow in narrow, crowded vessels. This could help design more precise methods for intravenous drug delivery, as well as 'microfluidic chips' incorporating artificial capillaries, which could offer faster, simpler and more precise blood-based diagnoses. ■

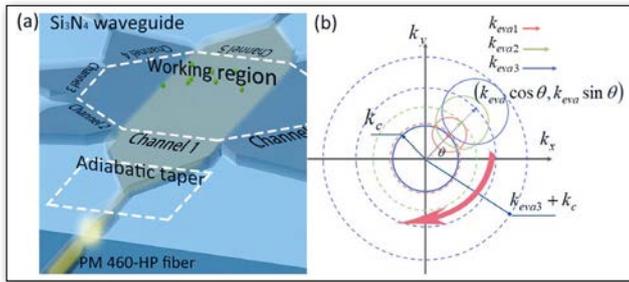
■ **G. R. Lázaro, A. Hernández-Machado and I. Pagonabarraga**

'Collective behavior of red blood cells in confined channels', *Eur. Phys. J. E* **42**, 46 (2019)

## APPLIED PHYSICS

### Chip-Based Frequency Shift Super-Resolution Imaging

Current label-free super-resolution methods suffer from either limited resolution improvements, small field-of-views or complex implementations, and a method with high-resolution, high-throughput and easy configuration is desirable for the practical applications in materials, biology and medicine, etc. To break this limitation, the authors propose a  $\text{Si}_3\text{N}_4$  waveguide platform design for multi-wavelength illuminated label-free super-resolution microscopy imaging. The deep-subwavelength resolution was enabled by large wave-vector evanescent illumination induced spatial frequency shift effect, which also provides the high throughput for its wide field implementation.



▲ Schematic and mechanism of the  $\text{Si}_3\text{N}_4$  waveguide based super-resolution chip.

In the method, chip-based waveguide with high refractive index produced evanescent wave illumination on the upper surface, the high tangential wave vector shifted the high spatial frequency components into the passband of the detection system from the perspective of the reciprocal domain. Multi-wavelength illuminated method was employed to cover the complete detection in the frequency domain. This enlarged the detectable broad-band frequency spectrum range, and high-resolution image with high signal-to-noise-ratio could be achieved using reconstruction algorithm. The optimized waveguide design to realize single mode behaviour and low attenuation guaranteed uniform evanescent wave illumination for the low-noise wide-field imaging. The integrated device is cost-effective, mass-producible and can conveniently give super resolvability to conventional microscopy as a compact module. ■

■ **X. Xu, X. Liu, Ch. Pang, Y. Ma, Ch. Meng, J. Zhang, X. Liu and Q. Yang,**

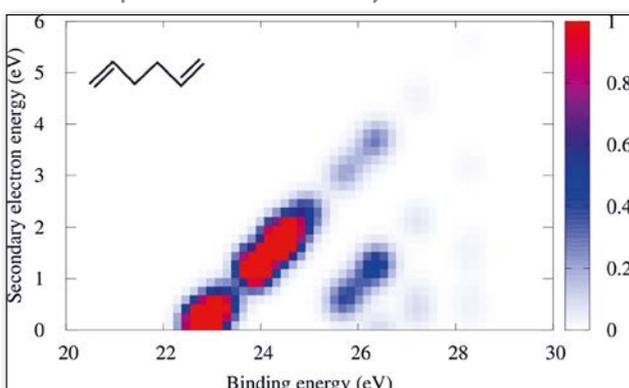
' $\text{Si}_3\text{N}_4$  waveguide platform for label-free super-resolution imaging: simulation and analysis', *J. Phys. D: Appl. Phys.* **52**, 284002 (2019)

## MOLECULAR PHYSICS

### Inner electrons behave differently in aromatic hydrocarbons

**A new study explores how the characteristics of aromaticity affect the process of Auger decay**

▼ Coincidence spectrum for benzene and other hydrocarbons.



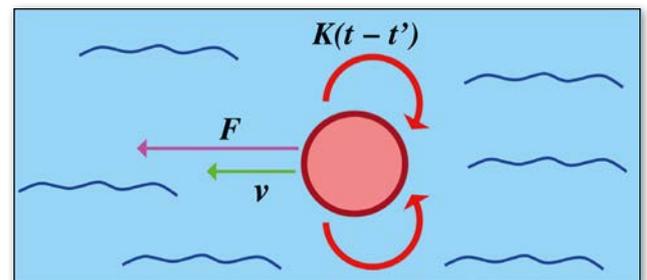
When an electron from one of the lower energy levels in an atom is knocked out of the atom, it creates a space which can be filled by one of the higher-energy electrons, also releasing excess energy. This energy is released in an electron called an Auger electron - and produces an effect known as Auger decay. Now, the authors have studied the Auger effect in four hydrocarbon molecules: benzene, cyclohexane, hexatriene and hexadiene. These molecules were chosen because they exhibit different characteristics of aromaticity. They found that molecules containing pi bonds have a lower threshold for Auger decay. Potential applications of this decay effect include a treatment called Auger therapy, which is used to help cancer patients. ■

■ **G. Zhao, T. Miteva, and N. Sisourat,**

'Inner-valence Auger decay in hydrocarbon molecules', *Eur. Phys. J. D* **73**, 69 (2019)

## STATISTICAL PHYSICS

### Is there memory for the memoryless?



▲ Overdamped Brownian particle under the influence of non-Markovian stochastic force.

Inertia plays a role on the evolution of Brownian particles. Nevertheless, the interplay of inertial time-scale contributions and an overdamped dynamics with non-Markovian stochastic forces leads to contradictions that make equilibration impossible. This is due to assuming memory correlations for the dissipation, which seems to be inconsistent with the overdamped approximation, where thermal fluctuations adjust instantaneously to the state of the particle. Effectively, by taking the noise correlation time-scale to be zero (no memory) we certainly recover the expected physical behaviour of the problem, e.g., the equilibrium distribution. On the other hand, we can deal with the contradiction by inserting another source of noise, of Markovian type, and with "effective temperature" different from the non-Markovian noise. As a result, the stationary state may be regularized and the equilibrium recovered if both noises have same temperatures, even for finite memory time-scales. The additional white noise brings the system back to equilibrium, no matter how small the new noise intensity is. ■

■ **E. S. Nascimento and W. A. M. Morgado,**

'Non-Markovian effects on overdamped systems', *EPL* **126**, 10002 (2019)

by Svetlana Lukishova<sup>1</sup>, Anatoly Masalov<sup>2</sup> and Victor Zadkov<sup>3</sup>

<sup>1</sup> Institute of Optics, Univ. of Rochester, USA – <sup>2</sup> Lebedev Physical Institute, Russia

<sup>3</sup> Institute of Spectroscopy, Russian Academy of Sciences, Russia – DOI: <https://doi.org/10.1051/epr/2019405>

## A lesson from the history of scientific discovery of measuring the pressure of light

In 2012, a memorial plaque was unveiled by the American Physical Society at Dartmouth College (Hanover, USA), which tells us that “At this site, ... from 1900–1903 E.F. Nichols and G.F. Hull performed the first precise measurement of the radiation pressure of light on a macroscopic body, as predicted by J.C. Maxwell in 1873. The Nichols-Hull experiment provided convincing evidence for the pressure of light, and the transfer of momentum between light and matter, a phenomenon which has enabled critical developments in a wide range of fields from atomic physics to biology to astrophysics.”

How did it happen then that the priority of the Russian scientist P.N. Lebedev in measuring the pressure of light was ignored? Here is our opinion on that.

Experiments on detection of light pressure on solids were undertaken at the beginning of the last century by P.N. Lebedev in Moscow, and by E.F. Nichols and G.F. Hull (N&H) at Dartmouth College (Hanover, USA). These scientists worked independently of each other. The first message of success came from P.N. Lebedev, who made a report on his measurements at the *Congrès International de Physique* in Paris in 1900. His report was published in the proceedings of the conference [1] in sufficient detail (7 pages). These results were also published in Russian in an article [2]. A more complete description of the experiments was published in 1901 [3], and in Russian in [4]. An English translation of paper [4] is presented in the book [5] (Chapter 12). N&H found out about the publication of P.N. Lebedev [1], and in December 1901 E.F. Nichols wrote a letter to P. Lebedev with a request for a reprint of Lebedev’s paper. N&H published their own results on measuring the light pressure in 1901 as a preliminary report [6] and in a complete form in 1903 [7]. The main conclusion which was deduced by N&H from their measurements [7] does not differ from the

conclusion of P. Lebedev in *Annalen der Physik* [3]: “Thus, the Maxwell-Bartoli theory confirmed quantitatively within the measurement error” with the distinction that this finding was published two years later. A particular result claimed by N&H was the value of the measurement error 1%, while P. Lebedev evaluated the accuracy of his measurements as 20%. This difference became the reason for considering the research of N&H as *the first high-precision light pressure measurement* (see the text on the memorial plaque).

The N&H statement about the 1% accuracy of the coincidence between the measurement results and the estimate of light pressure according to Maxwell’s theory was actually wrong.

First, to compare the experimental data on the pressure of light with the expected value, it is necessary to know the power of the acting light beam in absolute units. Until now, after a century of optical experiments, the absolute measurement of light power remains a delicate task. Calibration accuracy is usually only a few %; the most accurate meters claim 1% calibration accuracy. At the time of N&H it was impossible to imagine that the calibration of their source was performed with 1% accuracy. The only thing that can be agreed upon regarding the measurements of N&H is the 1% reproducibility of measurements. But this is not at all what can be called a 1% coincidence with the theory.

Then, a confirmation of doubts about 1% measurement precision can be found in a paper by M. Bell and S.E. Green [8], published in 1933. During their own measurements, they showed specific inaccuracies in the calculations of light pressure forces presented in N&H’s paper [7]. Correction of these factors, made by Bell and Green, led to a discrepancy of 10% between experimental data and the theory of Maxwell-Bartoli. In the Abstract to the paper [8] they wrote: “Although their (*Nichols*

and Hull's) work, carried out at a gas pressure of 16 mm of mercury, has been widely quoted as conclusively establishing, to within about 1 per cent, the numerical equivalence between the pressure and energy-density of radiation, it is found that their results, when correctly evaluated, show a divergence between these quantities of some 10 per cent. Hence Nichols' and Hull's investigation cannot be regarded as furnishing a quantitative experimental verification of the equality relationship deducible from theory." In a joint paper [9] Hull did also admit an error of some 10% (see also Chapter 13 in [5]).

This clearly proves that the Russian scientist was first to measure the pressure of light and that N&H independently confirmed his experiment with roughly the same accuracy.

Finally, the question arises why the APS decided to rewrite the history of scientific achievements? ■

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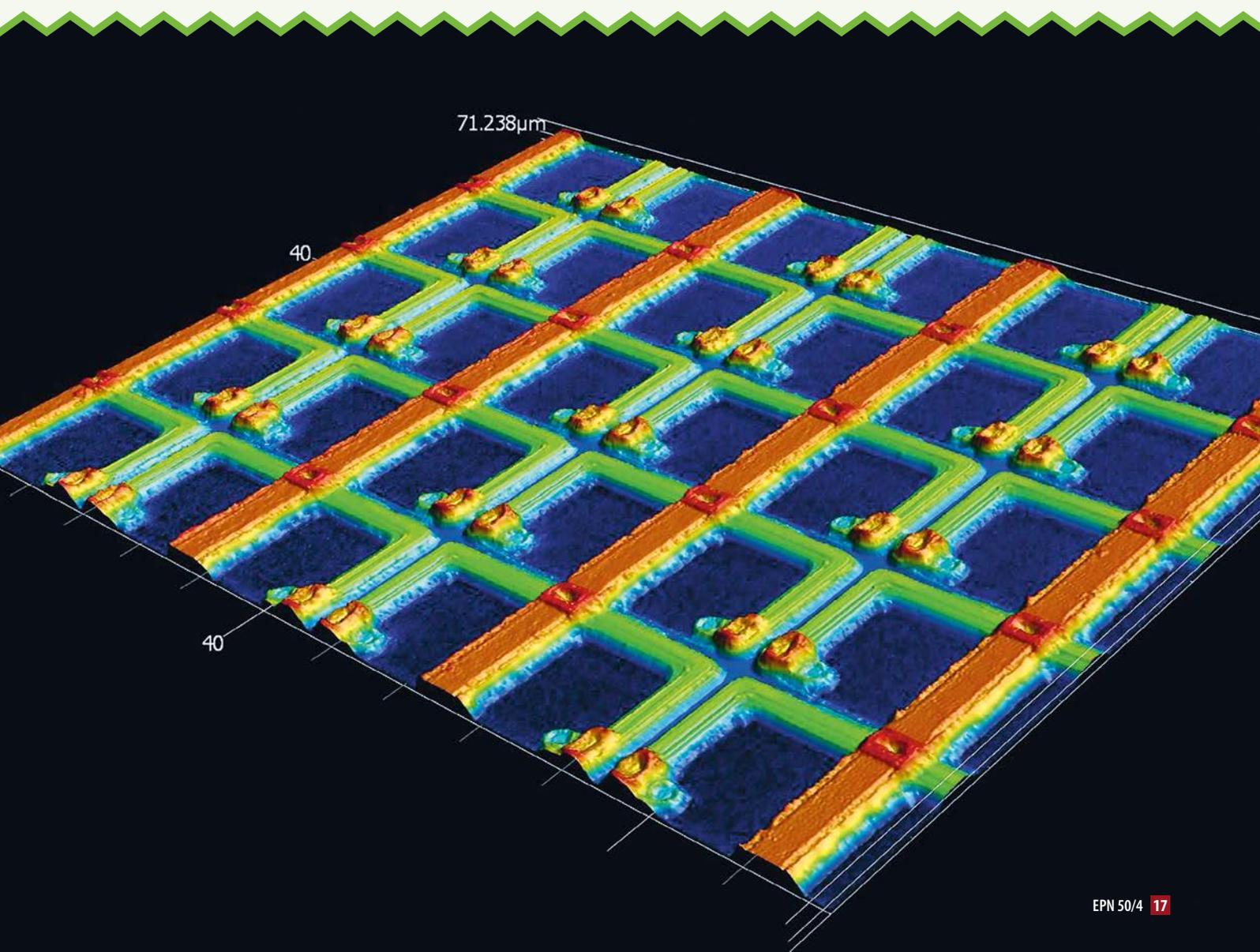
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# SILICON PHOTO-MULTIPLIERS

■ Robert Klanner – University of Hamburg – robert.klanner@desy.de – DOI: <https://doi.org/10.1051/e pn/2019401>

The measurement of single or few photons with a time resolution of 1 ns or below is an experimental technique with many applications in research, medicine and industry. Until recently, vacuum photo-multipliers (PMTs) dominated this field. In the 1990s avalanche photo-diodes came into use, and in the last decade solid-state photo-multipliers (SSPMs) have replaced PMTs in many applications. In most cases early samples, not yet optimised for the specific application, have been used. In the meantime industry and research institutes have significantly improved the performance of SSPMs.



◀ P. 17  
Microscopic view  
of a prototype  
SiPM from KETEK

### Principles of Operation

Silicon photo-multipliers (SiPMs) are arrays of hundreds to ten-thousands of Single-Photon Avalanche Diodes (SPADs) operated in Geiger mode above the break-down voltage. Every SPAD is connected to a quenching circuit – in most cases just a resistor – which stops the Geiger discharge. A photon, which converts in the SPAD into an electron-hole pair, can initiate a Geiger discharge resulting in a current pulse of charge Q (with  $Q = \text{product of (SPAD capacitance)} \times \Delta V$ , where  $\Delta V$  is the difference of bias and quenching voltage). Typical gains (Q-values for a single Geiger discharge) are between  $10^5$  and  $10^7$ . The SiPM output signal is the sum of all SPAD signals. As the signal of a single SPAD does not depend on the number of converting photons, SiPMs are digital detectors counting the number of SPADs with Geiger discharges. As shown in figure 1, the signals from a SiPM consist of narrow, well separated peaks corresponding to the different number of Geiger discharges.

One distinguishes analogue and digital SiPMs: In analogue SiPMs all SPADs are connected in parallel; in digital SiPMs every SPAD has its separate readout electronics. In the following we will concentrate on analogue SiPMs, as they are used in most applications today. However, recent progress in integrating SiPMs and 3D-CMOS technology shows the large potential of digital SiPMs for future innovative applications [2].

Figure 2 shows a specific example of the layout and the doping of a SPAD. A  $p^+$ -epi-layer, which forms the high-field region, is grown on a  $p^+$ -substrate. The diode is realised as an  $n^+$ -implant on top of an additional  $p$ -implant. The photons to be detected enter through the Anti-Reflecting-Coating (ARC). Between two SPADs additional  $p^+$ -implants isolate the SPADs electrically. The  $n^+$ -implants are connected via the quenching resistor to the top metal biasing lines, which connect the SPADs to the supply voltage. In order to optically separate two SPADs, trenches can be implemented as shown on the bottom.

An outstanding SiPM property is the high photon-detection efficiency (PDE), which can be achieved. The optimisation depends on the wavelength of the light and

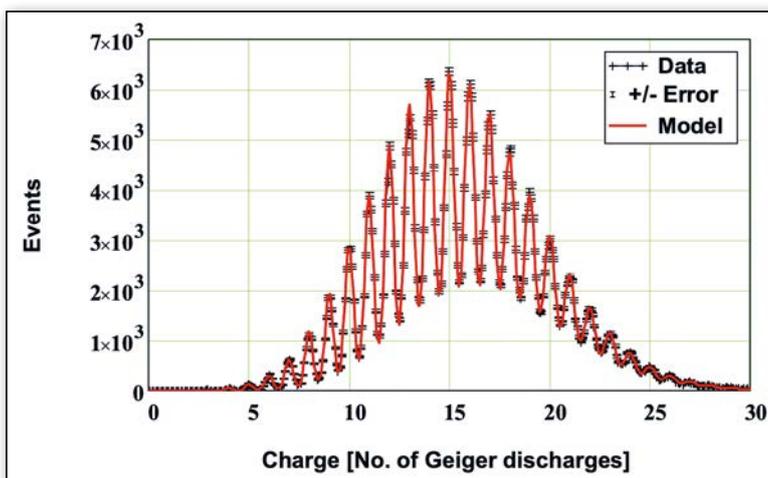
the SiPM operating temperature. The reason is that the light-absorption length in silicon changes from 10 nm for wavelengths between 75 and 350 nm to 10  $\mu\text{m}$  at 800 nm, and that the ionisation rates for holes and electrons are quite different and strongly temperature dependent. Figure 3 shows as an example how the PDE can be optimised by changing the diode design. The PDE is proportional to the probability that an electron-hole pair causes a Geiger discharge and increases with bias voltage. The voltage above the Geiger breakdown voltage is given in the figure. An additional challenge, in particular for SPAD sizes as small as  $10 \mu\text{m} \times 10 \mu\text{m}$ , is achieving a high fill factor, the ratio of sensitive area to total SiPM area.

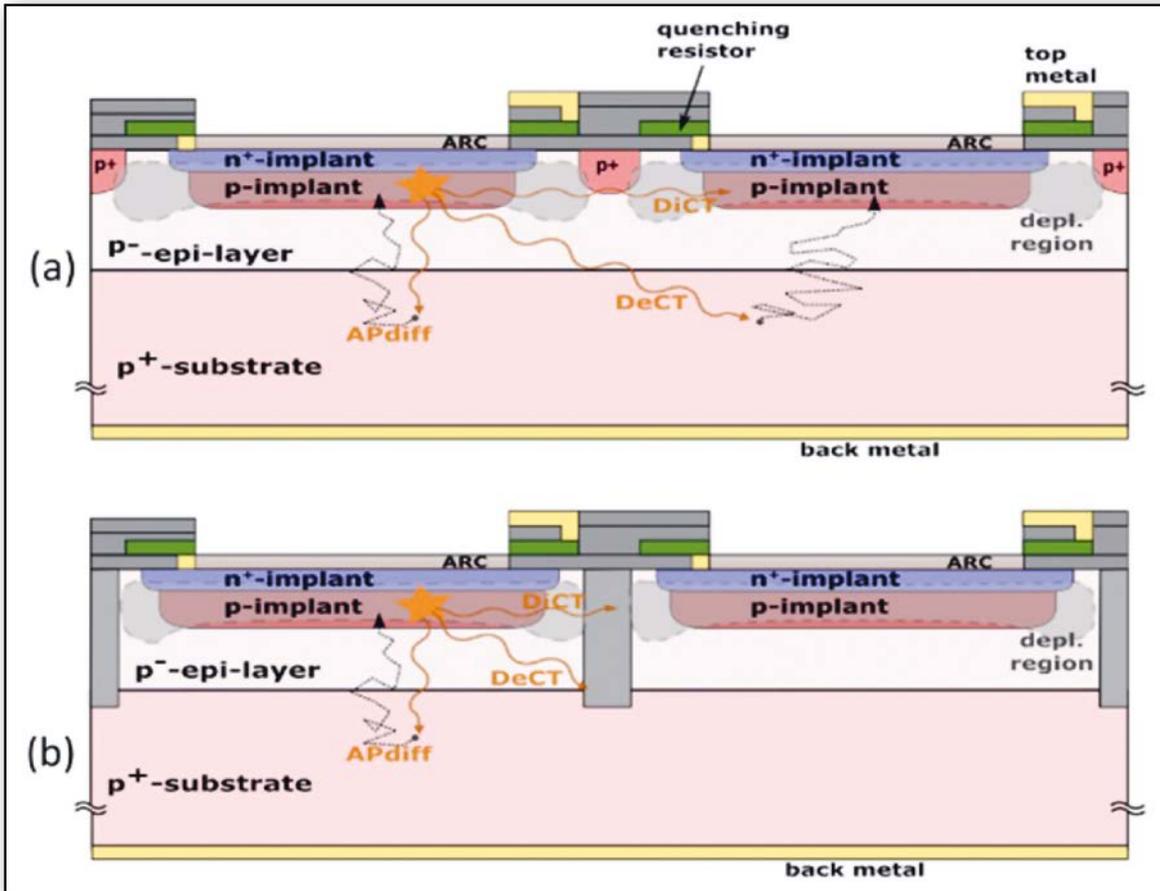
Different noise sources worsen the SiPM performance compared to ideal photo-detectors. As already a single charge can generate a Geiger discharge, the dark-count rate per unit area (DCR) of SiPMs is much larger than for PMTs. Typical DCRs at room temperature, where thermal generation dominates, are 100 kHz/ $\text{mm}^2$ . Cooling significantly reduces the DCR until band-to-band tunnelling dominates. For specific designs DCRs below  $10^{-2}$  Hz/ $\text{mm}^2$  have been reached at cryogenic temperatures [1]. Irradiation by hadrons results in a dramatic increase of DCR: An increase by 7 orders of magnitude for neutron fluences exceeding  $10^{13} \text{ cm}^{-2}$  is observed.

Cross-talk between neighbouring SPADs and after-pulses are other effects, which degrade the SiPM performance. During the Geiger discharge hot charge carriers emit photons, which can convert in the silicon. If they convert in the SPAD of the Geiger discharge, they have no effect, as the SPAD has not yet charged up to the bias voltage. However, if they reach a neighbouring SPAD, they produce a quasi-prompt Geiger discharge. This can be prevented by an opaque trench, as shown in figure 2. Care also has to be taken that photons do not reach SPADs via external optical paths. Photons also convert in the non-depleted substrate, and charge carriers can reach a SPAD via diffusion and generate delayed noise pulses there. In addition, charge carriers trapped in defect states in the silicon band gap can trigger delayed Geiger discharges, when they are released. All these effects are proportional to the number of charges in the Geiger discharge, and therefore proportional to the SiPM gain. They can be described by an Excess-Charge-Factor and an Excess-Noise-Factor, which parametrise the increase of the mean signal and the worsening of the signal spread compared to a Poisson distribution for the primary Geiger discharges.

SiPMs essentially count the number of converting photons, and their response is non-linear once the number of Geiger discharges is not small compared to the number of SPADs. Even for SiPMs with as many as 10 000 SPADs the dynamic range is significantly lower than for PMTs. Because of the recharging of the SPADs, the

▼ FIG. 1:  
Charge spectrum  
from a SiPM exposed  
to light from a  
sub-nanosecond  
laser. The peaks  
correspond to  
different number of  
Geiger discharges [3].





◀ FIG. 2: Cross-section of SPADs without (a) and with (b) trenches for optical isolation from [1]. Different sources of correlated noise, which are discussed in the text, are indicated. The depth of the p<sup>-</sup>-epi layer is one to a few μm.

non-linearity depends on the arrival-time distribution of the photons, and its understanding is quite complex. In addition, the SPAD signal shapes change with the number of simultaneously generated electron-hole pairs, an effect which is not yet understood in any detail.

Given the high field and the μm depth of the amplification region, SiPMs are intrinsically fast detectors with excellent time resolution. Resolutions of 20 ps (FWHM) have been achieved and further improvements are expected.

As solid-state detectors SiPMs are very robust and do not show signs of degradation, even when exposed to high light intensities. Another advantage is that they are simple to use and their operating voltage is only a few tens of Volts. However, as the break-down voltage and thus the gain changes with temperature, SiPMs have to be operated either in a temperature stabilised environment or with temperature regulation. Several such systems have been developed. For many applications it is also important that SiPMs are not affected by magnetic fields.

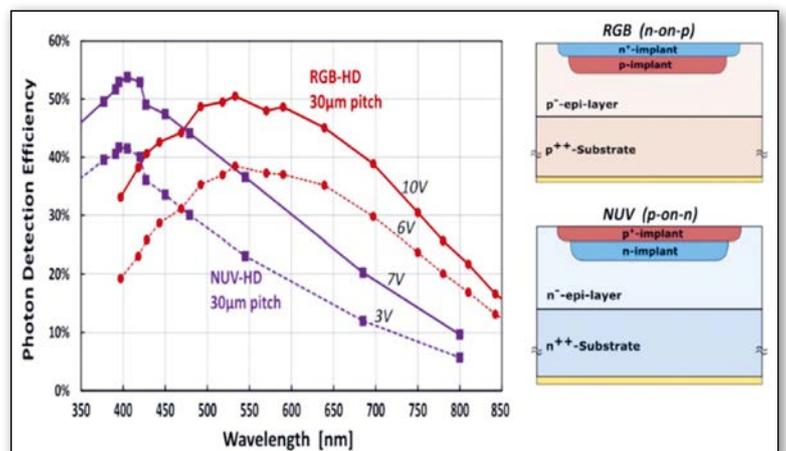
### Examples of SiPM applications

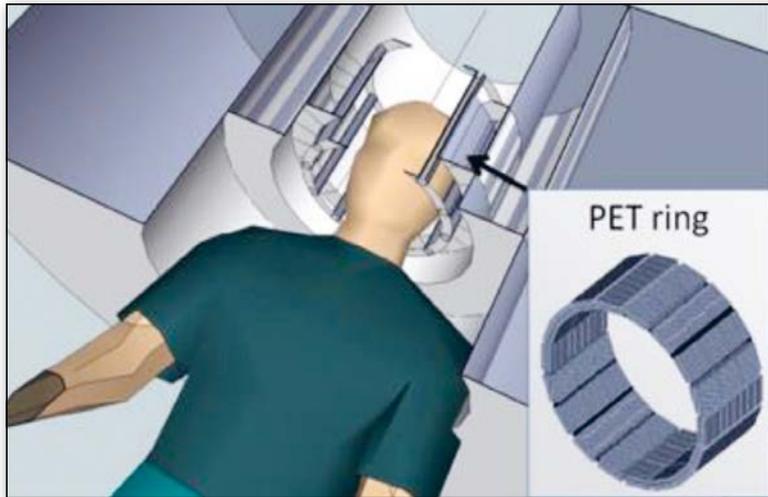
Already at the time of the first successful demonstrations of the SiPM concept in the late 1990s, the many possible applications had been realised [5]. However, it was also realised that different applications need different optimisations as discussed in [1]. Today SiPMs are used in fields as diverse as nuclear and particle physics,

spectroscopy, medicine, biology, and LIDAR (Light Detection and Ranging). As it is not possible to cover all these applications in a short overview article, only three examples are given.

The combination of Magnetic Resonance Imaging (MRI), which provides exquisite anatomical information, with Positron Emission Tomography (PET) giving functional information, is a major step forward in medical instrumentation. Given the high magnetic fields required for MRI, solid state photo-detectors, which are immune to magnetic fields, are ideal to realise MRI/PET systems. In addition, the precise time measurement can be used to suppress backgrounds. By now a number of systems e.g. for whole-body and brain scanning using SiPMs have

▼ FIG. 3: Photon-detection efficiency optimised for different wavelengths and the corresponding SPAD designs from [1].





▲ FIG. 4: Schematic drawing of the TRIMAGE scanner. The EEG cap is not shown [4].

been developed. In the innovative TRIMAGE project, Electro-Encephalo-Graphy is added to a PET/MRI scanner as a tri-modality imaging tool for schizophrenia [4]. Figure 4 show a schematic drawing of the TRIMAGE brain scanner.

The second example is Imaging Atmospheric Cherenkov Telescopes (IACT). They detect high energy gamma rays from the sky. With the discovery of more than 200 gamma-ray sources of galactic and extra-galactic origin, IACTs have contributed to better understand galactic nuclei, pulsars, black holes and the origin of cosmic rays. So far IACT detectors have used PMTs. IACTs detect faint flashes of Cherenkov light from particle showers in the atmosphere and can only operate during nights. The backgrounds from air glow, diffuse starlight and even worse from the moon, represent major limitations, with respect to measurement time and photo-detection stability. The stability of SiPMs when exposed to background light make them candidates for this application. Their

use for IACTs has been pioneered by the construction of FACT [6]. The FACT camera consisting of 1440 SiPMs with 3660 SPADs each has a diameter of 40 cm. It has been installed close to the MAGIC telescope at the Roque de los Muchachos observatory on the Island of La Palma in 2011, and tested by measuring the gamma-spectrum of the Crab-nebula between 250 GeV and 16 TeV. The results are in perfect agreement with the measurement of the MAGIC telescope, demonstrating the reliable performance of this new technology. Based on this success, CTA, the large Cherenkov Telescope Array, plans to use SiPMs for their cameras.

Excellent timing resolution and high photon sensitivity make SiPMs prime candidates for LIDAR applications, including automatic driving. In [7] the performance of a SiPM is compared to a PMT for atmospheric LIDAR in the same setup. Already for a non-optimised SiPM an improvement of the signal-to-noise-ratio by about 50 % for Aerosol observation up to a height of 3.35 km above ground level is observed. With optimised SiPMs significant improvements are expected.

## Conclusions

Solid-State Photo-Multipliers are relatively new detectors for measuring single and multiple photons with excellent time resolution. Already the first generation has found numerous applications and has replaced classical vacuum-photomultipliers in many measurement tasks. In the meantime, intensive R&D in academia and industry has resulted in significant performance improvements, and the use of solid-state photo-multipliers is expanding rapidly. ■

## About the Author



**Robert Klanner**, Prof. emeritus at Hamburg University. Experimental particle physicist, who contributed to the development of silicon sensors and calorimeters and their use in experiments.

## SUMMARY BOX

Silicon-Photo-Multipliers are arrays of hundreds to ten thousands of Single-Photon-Avalanche-Photodiodes operated in quenched Geiger mode above the break-down voltage. Given their excellent performance, they now replace Vacuum-Photo-Multipliers in many applications. Their photon-detection efficiency can exceed 50 % in a wide wavelength interval, they count single photons with a time resolution in the 20 ps (FWHM) range, operate at voltages of a few tens of volts, are insensitive to magnetic fields, are robust and do not deteriorate, even if exposed to strong light. However, their size is limited to about 10 cm<sup>2</sup>, their dynamic range is limited by the number of cells, and they have dark-count rates of tens to hundreds of kHz/mm<sup>2</sup> at room temperature. Their photon-counting resolution is influenced by optical cross-talk and afterpulsing. Developments in the last years resulted in major performance improvements and further progress is expected.

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# A TRIBUTE TO LISE MEITNER (1878-1968)

■ Henk Kubbinga – University of Groningen (The Netherlands) – DOI: <https://doi.org/10.1051/epn/2019402>

Physics is irresistible. Though prepared to become a teacher of French at an Austrian highschool, Lise Meitner, daughter of a lawyer, could not help coming under the spell of physics. By lucky coincidence she followed courses dispensed by no one less than Ludwig Boltzmann, whose wit and humour proved contagious. After her PhD, under Franz Exner, she moved on, not to Paris to work with Marie Curie, but to Berlin, to consult with Max Planck on future contingencies. Before leaving for Berlin, however, she was introduced to ‘radioactivity’ by Stefan Meyer.

▲ The Kaiser Wilhelm Institute for Chemistry, Berlin-Dahlem (courtesy: Archives of the Max-Planck-Gesellschaft, Berlin).

## Radioactivity anno 1905; Vienna

The supposed Röntgen-rays produced by uranyl, a uranium salt, had been identified by Marie Curie Skłodowska (1897-1898) to be an entirely new kind of spontaneous radiation by minerals, one that could be blocked by heaps of aluminium foil-sheets. In fact there were two kinds at stake: one of these radiations needed but a few sheets, the other several more. Rutherford called them  $\alpha$ - and  $\beta$ -rays, respectively. So much was sure: it was an atomic effect and new,

extremely active, elements were in the game (Po, Ra). Moreover, there were huge amounts of energy involved. Thorium minerals appeared to be even more ‘radioactive’ than pure uranium. Rutherford also noticed the *material* nature of part of the radiation: a current of air, caused by an open door, was enough to disturb the discharging of an electroscope. Were atoms a kind of ‘polymers’ of  $\alpha$ -particles and ‘radioactivity’ a matter of ‘depolymerisation’ or was it, more generally, a kind of ‘disintegration’?

These were the hot topics anno 1905. Though thrilled by Boltzmann's towering personality, his students in Vienna, among whom one Lise Meitner, did not learn much on the novelties. Meitner, though, heard of 'radioactivity' through Stefan Meyer, an assistant of Boltzmann. Following her PhD—under Franz Exner—on heat conductivity in inhomogeneous media, in February 1906, Meitner opted for the new field; already in July 1906 appeared her first singly-authored paper on the absorption of  $\alpha$ - and  $\beta$ -rays [1]. Another paper, one on the absorption and/or dispersion of  $\alpha$ -rays by sheafs of various metal foils (Ag, Cu, Pt and Sn), followed in 1907 and brought her to settle a matter which opposed Ernest Rutherford, on the one hand, and Bohumil Kučera and Bohuslav Mašek, on the other, to William H. Bragg. Accidentally, Meitner made the acquaintance of Max Planck, on visit in Vienna as a candidate to succeed to Boltzmann.

### From Vienna to Berlin (1907); Otto Hahn

'Radioactivity' was the topic of the day, not—not yet—quanta or photons. The place to be was either Paris, London, Berlin, or Prague. With dreams of an Austria united to Germany, Meitner opted for Berlin. She inquired with the generally beloved Planck, who had been nominated as the new editor-in-chief of the *Annalen der Physik* and who, though not a shadow of the spirited Boltzmann, taught Theoretical Physics. With her taste for experimental work, she also approached Heinrich Rubens. Again no problem: she got a place in his laboratory and enrolled for the Physics Colloquium. A charming lad, one Otto Hahn, a radiochemist who had just returned from a trip to Ramsay (London) and Rutherford (Montreal), used to be there, too. Hahn was already an authority in the field, but couldn't help remaining a drop-out among the Berlin chemists. A lifelong comradeship in science was born.

Meitner and Hahn opted for a study of  $\beta$ -rays, first through their absorption and/or dispersion behaviour, later through their curvature in magnetic fields (Fig.2). The identity of these rays with those of the discharge tube appeared *i.a.* by letting a flat beam graze over a perpendicular screen covered with fluorescent material: by applying a magnetic field the beam curved indeed (Fig.3). What is more, the initial beam split up, suggesting the presence of particles of discrete velocities, and hence different sources (Fig.3 and 4). In 1912 Hahn and Meitner came to focus on the actinium-series, where a mysterious sequence of  $\alpha$ - and  $\beta$ -emitters seemed to hint at an as yet unknown precursor. Atomic and nuclear physics were booming: Soddy coined the notion 'isotope', Moseley revealed the role of the nuclear charge in a Rutherford-Bohr kind of atom. The 'replacement laws' were formulated: release of an  $\alpha$ -particle implied the production of an element two places backwards at the Periodic Table, release of a  $\beta$ -particle of an element one place forwards.

The Great War changed a lot: all over Europe young scientists, like any other section of the population, enthusiastically joined the various armies. Hope was in the air, on all sides, though science suffered. Marie Curie and her Irène organized the Röntgen-Department of the French army, Meitner came to do something similar on the German-Austrian side. From time to time she returned to Berlin to continue the elucidation of the actinium series, in sustained correspondence with Otto Hahn; Hahn himself also showed up every now and then. In the case of actinium it struck that it was only found in U-ores, that is, in *any* U-ore whatsoever, and so in a small though constant proportion. Actinium's half-life was estimated at 30 years, which implied that it could impossibly be the first term of a series, let's say, like U. The conclusion imposed itself that actinium and its derivatives represented a branching off from the already well-known U-series and that there should exist another species serving to bridge the gap between U and Ac. With the Periodic Table at hand a possible route to Ac could be designed: knowing that  $\alpha$ -active U features in Group VI, it was clear that its derivative belonged to Group IV, had valency 4 and ought to be, therefore, an isotope of thorium. There were two candidates: 'ionium', the  $\alpha$ -active mothersubstance of radium, and a  $\beta$ -active isotope, the two produced in the ratio of 97 : 3. Actinium, then, should

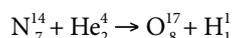
▼ FIG. 1: Lise Meitner (1947) by her sister-in-law, Lotte Meitner-Graf (courtesy: National Library of Austria, Vienna).



be related to that  $\beta$ -active Th-isotope. Since actinium's chemistry had shown that it belonged to Group III, that of lanthanum, it was clear that it derived from a bivalent  $\beta$ -emitter or a pentavalent  $\alpha$ -emitter. The only bivalent candidate was  $\alpha$ -active Ra, so the choice to be made was for the other, the pentavalent species, similar to tantalum. It was this line of reasoning which led to the identification of the new element, which was baptized, in a paper co-authored with Hahn, 'protactinium' [4]. By then, Meitner headed, as Professor, the newly created Physics Section of the Kaiser-Wilhelm Institute for Chemistry and went her own way, at least for a while.

### The neutron and its transuranium promises (1919, 1932)

In 1919 Rutherford had directed a source of  $\alpha$ -particles at nitrogen gas when he noticed the appearance of flashes upon a ZnS-screen far beyond the range of the  $\alpha$ -particles themselves. Highly energetic lighter particles were in the game, provisionally called 'protons'. Obviously, some of the N-atoms had been affected in the process, a case of an *artificially* induced nuclear reaction. It was not yet clear how, precisely: were there two or three particles produced? The cloud chamber, then, showed that there were just *two* tracks, suggesting that the He-nucleus was absorbed, the 'proton' being expelled:



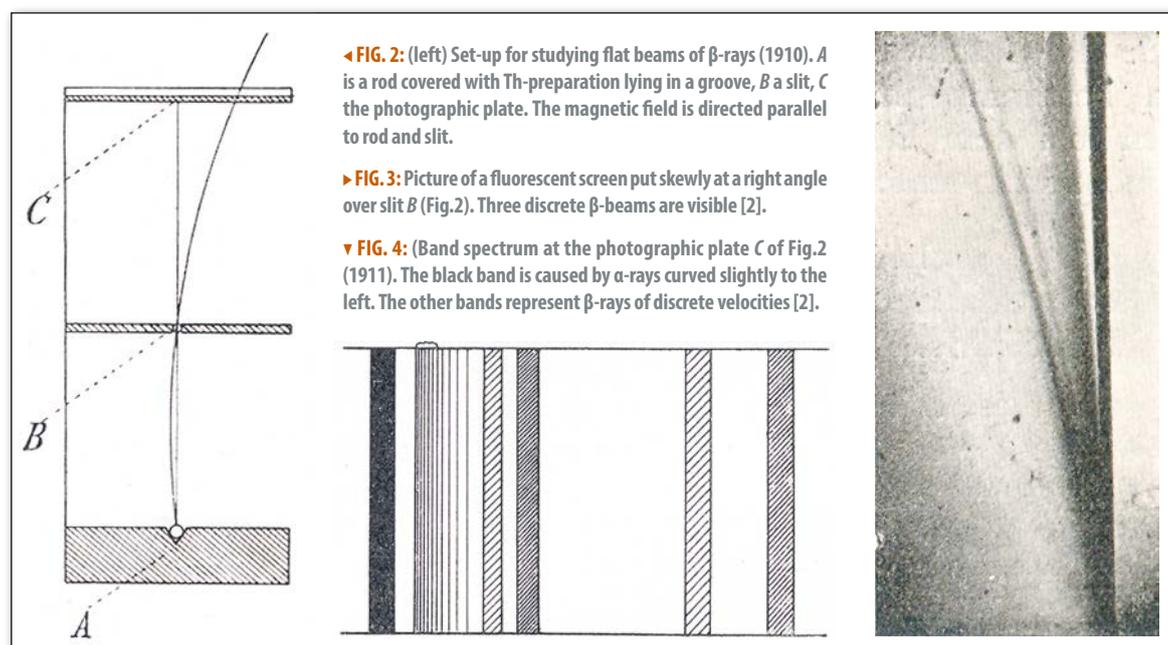
Rutherford, then, adapted his earliest hypothesis, taking nuclei now as clusters of  $\alpha$ -particles and free 'protons';  $\beta$ -particles were indispensable, if only to account for the required charge. Hence Rutherford's idea of a *neutral* particle consisting of a proton and an electron; he called it a 'neutron'. Through the eyes of Meitner—it is 1921—this implied that she could write down the nuclei of

the successive elements of the Periodic Table and their isotopes, and foretell approximately how an eventual reaction would proceed on bombarding them with  $\alpha$ - or  $\beta$ -particles. For instance, a classic, the  $\text{U}_{92}^{238}$ -nucleus, could be considered as a whole of 46  $\alpha$ -particles, 13 He-atoms, 2 H-ions and 2 free electrons, in Meitner's notation written as follows:

$$46\alpha + 13(\alpha' + 2\beta) + 2\text{H}^+ + 2e$$

Conversely, it was possible to predict the existence of as yet unknown moieties. In order to further study the variables of such experiments she devised a cloud chamber of her own and measured the effects of condensable vapours other than water and those of other carrier gases than air (1924). The  $\gamma$ -rays typical for  $\beta$ -decay puzzled her: they might originate from  $\beta$ -particles transformed into energy, as she thought initially, or come from energy transitions in the nucleus. On leaving the nucleus they caused at any rate an internal photo-electrical effect, causing the continuous  $\beta$ -spectrum as observed most of the time.

Following the identification of the 'neutron' and the discovery of the 'positron' and the 'deuteron', the 7<sup>th</sup> Solvay Conference on Physics came to be devoted to the structure and properties of nuclei; it was convened at Brussels in October 1933, with Meitner (and Fermi) among the invited guests. Bombarding uranium with 'neutrons', produced by Po- $\alpha$ -particles hitting a Be-target, seemed the natural way to create isotopes eventually featuring  $\beta$ -decay leading to new elements, heavier than uranium. Fermi and his team claimed, in May 1934, to have found two such 'transuranes'. Meitner was on top of all this, naturally. As the expert in the field she was also key-note at the Mendeleev centenary in Leningrad, on 11 September 1934, with a lecture on the relation between nuclei and the Periodic Table. Back home, she





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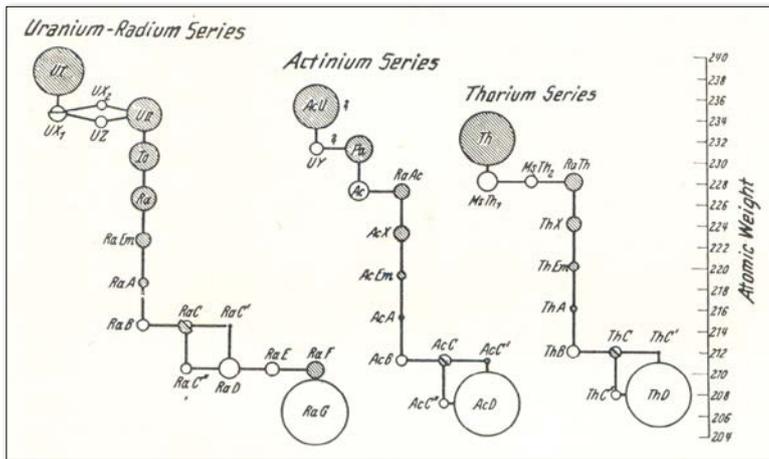
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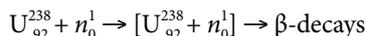


▲ FIG. 5: The three disintegration series anno 1936 [3]. The radii of the circles are a measure for the stability; shaded circles indicate  $\alpha$ -radiators, open circles  $\beta$ -radiators. On the right we see 'atomic weight' ('mass number').

decided to rework her talk into a review-like booklet; Max Delbrück, a post-doc, signed for the theoretical part (Fig.6). Stability, we read there, e.g. that of the He-nucleus, was a crucial notion, to be defined in terms of the mass-defect. And also:  $\beta$ -particles and the newly discovered positrons did not exist as such in the nucleus; their production revealed interconversions of protons and neutrons. Hahn and Meitner, in touch with Fermi and the Joliot-Curies, decided to see if they, too, could bring about artificial radioactivity and confirm in one way or another the existence of transuranes.

### Joining forces, again; nuclear fission (1938/39)

Bombarding the  $U_{92}^{238}$ -nucleus with neutrons produced about nine  $\beta$ -activities, among which doubtless one or more transuranes or eka-homologs of the elements Re, Os, Ir, Pt and Au:



Hahn, Meitner and their collaborator Strassmann considered three parallel  $\beta$ -decay series involving nuclear 'isomers', something new and imperative, if only to account for the numbers. The chemical separation proved puzzling all the same: when all the presumed transuranes precipitated as low soluble sulphides by adding  $H_2S$  to an HCl-solution, there remained an activity in the liquid, which behaved as if a Ra-isotope was at stake, since it coprecipitated with Ba-salt, a standard procedure with Ra. A further separation failed, however: was the presumed Ra nothing but Ba? In the week before Christmas 1938 Hahn informed Meitner, by now in Stockholm, on the estranging finds: uranium producing barium, how could that be? Meitner was shocked, but, as she wrote by return mail, nuclear physics had already caused more 'impossible' surprises. On reconsidering Hahn's results, together with her nephew Otto Frisch on vacation in Stockholm, she concluded that apart from barium ( $Z = 56$ ) the uranium had produced xenon ( $Z = 36$ ) and that huge amounts of energy were at stake. Nuclear 'fission' got its name. It appeared to be a 'classical' process

▼ FIG. 6: Titlepage of Dirk Coster's private copy of Lise Meitner and Max Delbrück's monograph *Der Aufbau der Atomkerne* [5].



in that the nucleus behaved like a droplet of a liquid, with shape variations which could be overagitated by neutron capture, bringing about the observed splitting up into two highly repulsive parts. The eka-'isomers' of before became various Ba- and Xe-isotopes, depending on the neutron numbers, each with a decay period of its own.

If the grandeur of Meitner and Hahn is in their epochal partnership, the petitesse was brought by history. On leaving Berlin for Groningen with Dirk Coster, that Wednesday, July 13<sup>th</sup>, 1938, Meitner received from Hahn the diamond ring of his mother to help her overcome eventual formalities. During the blood-curdling voyage Meitner, though, got irritated by that unusual item on her finger. Coster, then, took it over and slipped it into the pocket of his waistcoat. The ring survived, but it was robbed from its diamond; the stone was used to further embellish an already overloaded other ring .... Vanity of vanities, all is vanity. ■

### Acknowledgment

I am greatly obliged to Anne Meitner (Cambridge), daughter of Lotte Meitner-Graf, for helping to revive the past; to Athene Donald, Director of Churchill College, Cambridge, for permission to consult the papers of Lise Meitner; to Kristina Starkloff, Director, and Susanne Uebele of the Archives of the Max-Planck-Gesellschaft, Berlin; to Peter Prokop, Head of the Picture Collection of the Austrian National Library, Vienna; and to Rolf Siemssen (University of Groningen) for kind consultation.

### About the Author



**Henk Kubbinga** is a historian of science at the University of Groningen and member of the EPS-HoP-Group. Actually he is finishing the fifth and last volume of *The collected papers of Frits Zernike* (1888-1966).

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# THE BIOPHYSICS COLLABORATION FOR RESEARCH AT FAIR

## AND OTHER NEW ACCELERATOR FACILITIES

■ Marco Durante<sup>1,2</sup>, Yolanda Prezado<sup>3</sup> and Vincenzo Patera<sup>4,5</sup> – DOI: <https://doi.org/10.1051/epn/2019403>

■ <sup>1</sup> GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany – <sup>2</sup> Technische Universität Darmstadt, Germany

<sup>3</sup> CNRS, Orsay, France – <sup>4</sup> University of Rome “La Sapienza”, Italy – <sup>5</sup> INFN ROMA1, Rome, Italy.

Applied nuclear physics is ubiquitous in our lives, and is a field in fast and exponential growth. Biomedical application at particle accelerators are particularly important, and many current accelerators in Europe built for nuclear physics (e.g. GSI in Germany, KVI in The Netherlands, GANIL in France, INFN-LNS in Italy) have intense and productive biomedical programs covering topics such as radiotherapy with charged particles and radiation protection in space [1].



◀ P. 27: The GSI Helmholtz Center in Darmstadt, and the FAIR construction site in September 2018. Photo: T. Middelhaue/GSI/FAIR

There are now several new accelerators under construction worldwide, that offer new opportunities for the researchers. Most of these very expensive facilities plan biomedical research. But what can the new facilities offer to researchers in biology and medicine worldwide? How should we coordinate the efforts to avoid duplications and instead have synergistic interactions for biomedical research at new accelerators? To address the issue, an International Biophysics Collaboration has been established at the Facility for Antiprotons and Ion Research (FAIR). The first meeting of the Collaboration was held at GSI (Darmstadt, Germany) on May 20-22, 2019 (Figure 1).

FAIR is the new international accelerator facility presently under construction at the site of the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany (Figure 1). The new facility, where various physics programs can be operated in parallel, will offer outstanding research opportunities and discovery potential for about 3000 scientists from about 50 countries. International Collaborations in hadronic physics, nuclear structure *etc.* are already actively working to prepare the experiments for the opening of FAIR [2].

FAIR also hosts an intense and innovative program in applied nuclear physics (APPA) [3], and in particular in biophysics. The expertise stems from the activity of the Biophysics Department at GSI, funded by Prof. Gerhard Kraft, that has pioneered carbon ion therapy in Europe [4] and currently runs the experimental program for space radiation research supported by ESA (IBER program) [5]. In fact, FAIR can offer unique opportunities for biomedical research. The production of very high energy ( $\sim 10$  GeV/n) heavy ions is very important for studies in space radiation protection, both in biology and microelectronics. The high energy can also be used for particle radiography and theranostics, whereas the high intensity of the FAIR beams gives opportunities for using high-energy radioactive ion beams and ultra-high dose

rates in particle therapy, and for the production of new radioisotopes (Figure 2) [6].

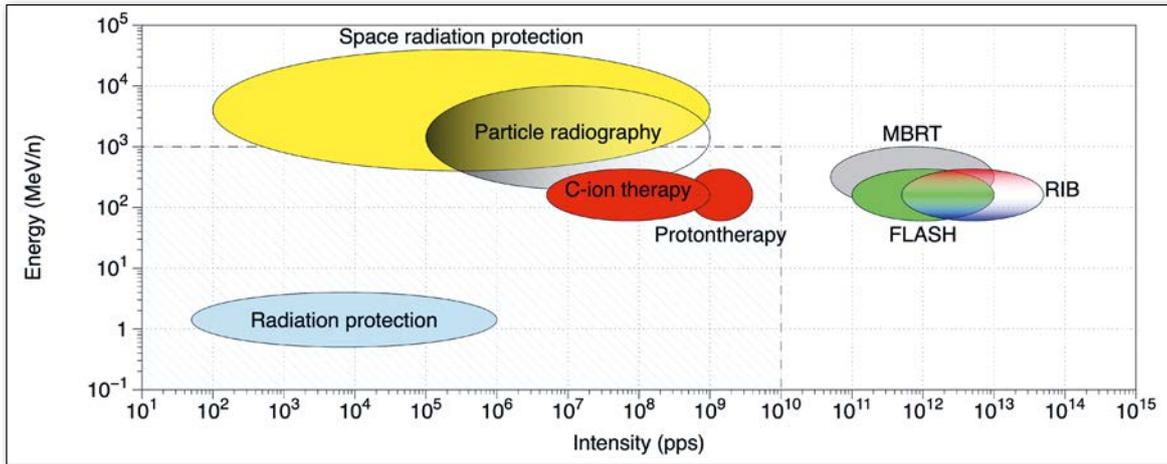
Similarly to the other FAIR collaborations such as NuSTAR, PANDA, and CBM, the Biophysics Collaboration held a meeting at GSI/FAIR on May 20-22, 2019. With 250 participants from 27 countries in 5 continents, the meeting demonstrated the enormous interest of the scientific community for the biomedical applications at FAIR (figure p.27).

Several new ideas for experiments at FAIR have been proposed. As shown in Figure 3, high-energy heavy ions are particularly attractive for space radiation protection. In fact (Figure 3), FAIR covers a region of the galactic cosmic ray spectrum which is currently only measured by detectors in space such as the alpha-magnetic spectrometer (AMS) on the International Space Station, but that contributes around 60% of the effective dose to astronauts behind thick shielding [7]. High-energy heavy ions are therefore necessary to measure the biological effectiveness of the ions and to measure shielding effectiveness against cosmic rays (Figure 4). For this reason, it is also important to simulate the full LET spectrum of the galactic cosmic radiation, a facility already available at the NASA Space Radiation Laboratory (NSRL) [8] in Upton, New York, and now planned at FAIR [9].

The high energy makes also possible new solutions in particle therapy. In fact, proton radiography is generally acknowledged as the best method to reduce the uncertainty associated to the conversion of the Hounsfield units (HU) from the CT scans in the water-equivalent path-lengths (WEPL) necessary for proton therapy treatment planning [10]. The image is obtained with X-rays, but the treatment is done with charged particles, hence the HU/WEPL conversion is critical. If the image is directly obtained with protons, this uncertainty is automatically cancelled. Conventional proton radiography projects are bound to low energy ( $<250$  MeV) and are therefore only applicable to selected tumor sites (typically the

▼ FIG. 1: Group photo at the Biophysics Collaboration Meeting at GSI, May 20, 2019. Photo by Gabi Otto, GSI.





◀ **FIG. 2:** Biomedical applications at new accelerators. The shaded rectangle includes the (E, I) region covered by particle accelerators. FAIR will provide higher energy and intensity thus allowing experiments in space radiation protection and particle therapy not possible at current heavy ion accelerators. MBRT= minibeam radiotherapy; FLASH = ultra high dose-rate therapy; RIB = radioactive ion beams for therapy and beam visualization. Image from ref. [6]

head-and-neck region). Using this relatively low energy proton beam the technique is plagued by the image blurring caused by the strong elastic scattering of the primary beam, well described by the Molière theory. These problems are overcome using protons with energies ~GeV and the PRIOR setup built by the plasma physics collaboration at FAIR, where also body tumors can be visualized with high spatial and temporal resolutions [11]. The PaNTERA experiment at FAIR will explore the possibility to use 4.5 GeV protons for radiography and tomography with sub-mm resolution.

The high-intensity offers even more opportunities for particle therapy. In fact, spatially fractionated radiotherapy (SFRT) uses a grid structure to reduce toxicity in normal tissues, thus widening the therapeutic window. So far limited to brain tumors, the high-intensity can allow extensions to body regions, where the movements jeopardize the spatial fractionation. Already successfully tested in animal models with protons [12], at FAIR there is the opportunity to perform these experiments with very heavy ions [13]. In the pilot project at the Lawrence Berkeley Laboratory in the 70-80s, ions as heavy as 40Ar were used in selected patients [14]. The rationale was that only these heavy ions can overcome hypoxia resistance in some aggressive cancers. However, ions heavier than 12C were abandoned in the clinical applications in Asia and Europe, because of the excessive toxicity of very heavy ions in normal tissues. Using SFRT, normal tissue will be spared making attractive the use of heavy ions against very hypoxic tumors. The possibility of using very high energies (> 1GeV/u) permits the exploration of new avenues in charged particles minibeam radiotherapy [15].

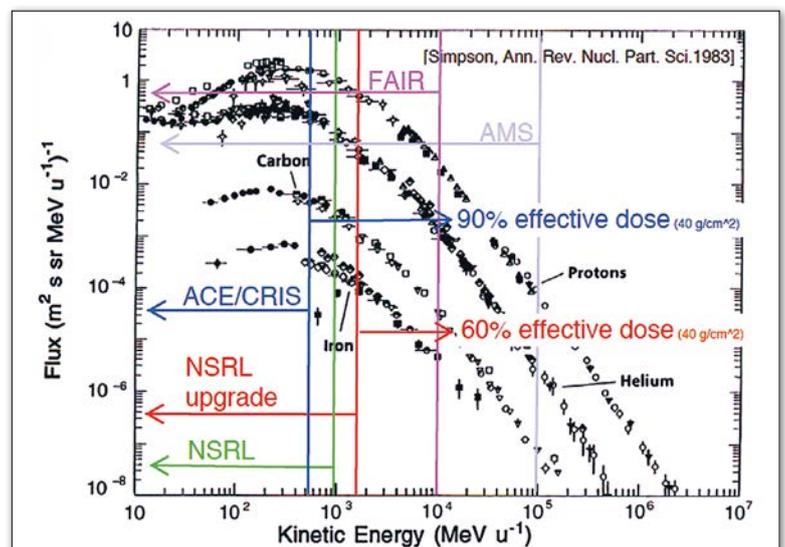
Recent experiments have shown that ultra-high dose rates (>40 Gy/s) spare normal tissue but do not compromise tumor control in animal models (FLASH radiotherapy) [16,17]. These high intensities have been so far achieved with electrons in modified linacs and with protons at cyclotrons [18], but at FAIR it can be tested with heavy ions.

Radioactive ion beams provide a very high signal/noise ratio for online PET imaging and do not suffer from the shift between the peak of the activity and the Bragg peak observed using fragments of stable 12C ions [19]. Short half-life  $\beta^+$ -emitting nuclides, such as 10C ( $t_{1/2} = 19.29$  s), allow truly online beam monitoring with PET detectors. Although already proposed during the pilot project in Berkeley [20], use of radioactive ions in therapy was always hampered by the low intensity. Now these isotopes can be produced at therapeutic intensities at FAIR.

With the start of FAIR-phase-0 in February 2019, these high-intensity experiments are already feasible at the SIS18 synchrotron of GSI. The high energy will be available at SIS100, whose opening is foreseen in 2025.

Unlike other detector-centered collaborations, the International Biophysics Collaborations goes beyond FAIR. In fact, there are many new accelerator facilities under construction all over the world (e.g. NICA in Russia, RAON in Korea, FRIB in USA, ELI, SPIRAL2 and SPES

▼ **FIG. 3:** The energy spectrum of H, He, C and Fe ions in the galactic cosmic radiation in deep space. Vertical bars indicate the maximum energies achievable with ground-based accelerators or radiation detectors in low-Earth orbit. ACE/CRIS= Cosmic Ray Isotope Spectrometer (CRIS) on the Advanced Composition Explorer (ACE) spacecraft; NSRL = NASA Space Radiation Laboratory; AMS = Alpha Magnetic Spectrometer. Plot courtesy of John W. Norbury, NASA Langley, VA, USA.





▲ FIG. 4: Tests of Martian regolith at the SIS18 accelerator at GSI. Shielding can be exposed to high-energy heavy ions to measure the dose attenuation and the production of neutrons and charged secondaries. Photo by Gabi Otto, GSI.

in Europe, etc.) where applied nuclear physics programs are planned and biomedical research will be possible. The International Collaboration will serve all these facilities and will develop research programs and specific devices for use at various accelerators. Accelerators currently operating for biomedical research are also part of the collaboration and contribute with their local research program and with hardware to be built with the other facilities. Experimental collaborations in biophysics are already active in FAIR-phase-0 (e.g. PaNTERA [11], FOOT [21] and IBER [5]) and the Biophysics Collaboration has the task to supervise and support these experimental activities also in funding applications.

Vincenzo Patera (University of Rome “la Sapienza”, Italy) and Yolanda Prezado (CNRS, Orsay, France) have been elected spokesperson and deputy spokesperson of the collaboration respectively. The collaboration webpage is: [www.gsi.de/bio-coll](http://www.gsi.de/bio-coll) ■

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**Marco Durante** is Director of the Biophysics Department at GSI Helmholtz Center for Heavy Ion Research (Darmstadt, Germany) and Full Professor of Physics at the Technical University of Darmstadt. He is generally recognized as world leader in the field of particle radiobiology and medical physics and is co-author of over 300 papers in peer-reviewed scientific journals (h-index=45) and one patent on proton therapy. He has been awarded several prizes for his contributions to charged particle biophysics.



**Vincenzo Patera** is Full Professor in Physics at Rome University “La Sapienza”, Istituto Nazionale di Fisica Nucleare (INFN) associate and Centro Studi e Ricerche Enrico Fermi associate. He started his career as experimental particle physicist, working on high energy penetrating cosmic rays and then on CP violation and quark mixing matrix. Since 2007 he is coordinator of the Applied Radiation Physics Group. He is spokesperson of several international collaborations and principal investigator of different projects.



**Yolanda Prezado** is a permanent scientist at CNRS (France). She holds a Diploma in Advanced Studies in Particle Accelerators (2000) and a Ph.D. in Experimental Nuclear Physics (2003). She is a board-certified medical physicist (2007), with clinical experience. She has been developing her research in radiation therapy with research interests including Grid and minibeam radiation therapy, dose calculations (Monte Carlo simulations), small field dosimetry and radiobiology. She is currently the chair of the Science Committee of the European Federation of Medical Physics (2019-2020, elected).

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**High intensity is useful for several therapy-related applications such as FLASH, minibeam, and radioactive ion beams**

# SEEIIST

## SOUTH EAST EUROPEAN INTERNATIONAL INSTITUTE FOR SUSTAINABLE TECHNOLOGIES

■ Sanja Damjanovic<sup>1,2,3</sup> on behalf of the Intergovernmental SEEIIST Steering Committee<sup>4</sup>

■ <sup>1</sup> Ministry of Science of Montenegro, Montenegro – <sup>2</sup> GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

<sup>3</sup> Chairperson of the SEEIIST Steering Committee – <sup>4</sup> <https://seeiist.eu/members> – DOI: <https://doi.org/10.1051/epn/2019404>

The states in South East Europe are joining forces to set up a large-scale competitive research infrastructure – the South East European International Institute for Sustainable Technologies (SEEIIST, <https://seeiist.eu>). Due to the recent history in South East Europe all scientific and economic activities have very much slowed down. As a consequence this region has suffered ever since from a strong brain drain of the young generation, affecting in particular the best.

In contrast, the same region had in the past an intensive technological development and made significant scientific contributions on an European scale. Prime examples are the first research nuclear reactor in this region operated already in 1959, just two years after such a research reactor started operation in Germany, and the role of the region as one of the founding members of CERN in 1954. To recover this tradition, *i.e.* to decrease the present large gap compared to the rest of Europe and to revert the brain drain, the most efficient way is to establish a large-scale internationally competitive research infrastructure in South East Europe.

The objective of this project is to foster regional cooperation in the fields of science, technology and industry in the spirit of the CERN and SESAME models ‘Science for Peace’. This would greatly help to address common challenges and needs in SEE, helping in particular to develop sustainable economy and social cohesion. Capacity building and the slowing down if not reversal of the brain drain would become immediate benefits.

About two years ago the Government of Montenegro initiated the establishment of the SEEIIST Project, originally proposed by Prof. Herwig Schopper, a former Director General of CERN. This Initiative was formalized as a Regional project after signing a **Declaration of Intent** on 25 October 2017 at a Ministerial meeting at CERN (Figure 1, top). The Signatory Parties were Albania, Bosnia and Herzegovina, Bulgaria, Kosovo<sup>1</sup>, Montenegro,



FIG 1: Signature of Declaration of Intent at CERN by Ministers of Science/Corresponding Ministers (top); Signature of Memorandum of Cooperation by Prime Ministers of the Region at the Summit of the Berlin Process at Poznan (bottom).



<sup>1</sup> This designation is without prejudice to positions on status and is in line with UNSC 1244/1999 and the ICJ opinion on the Kosovo Declaration of Independence

Serbia, Slovenia and North Macedonia. Croatia and Greece took an observer status. Most recently, a SEEIIST **Memorandum of Cooperation** was signed by six Prime Ministers of the Region on 5 July 2019, at the occasion of the Summit of the Berlin Process at Poznan, Poland (Figure 1, bottom).

The core of the Project is a **‘Facility for Tumour Therapy and Biomedical Research with Protons and Heavier Ions’** which today present the most modern and most successful method for treating a large number of different cancer types. In Europe, four facilities of this kind exist, in Germany HIT in Heidelberg (Figure 2, left) and MIT in Marburg, CNAO in Pavia/Italy and MedAustron in Vienna/Austria. However, such a therapy centre does not exist in the SEE Region, where a perpetually growing number of tumours have been registered in recent years. Heavy ion treatments are still in the pioneering phase. Beyond the treatment of patients, it is therefore planned to dedicate 50% of the beam time to research with multi-ion sources (beyond presently used protons and carbon ions), making the SEEIIST project unique in the world. With its double task to treat patients and to perform research, the SEEIIST project would present one of the best examples of **‘Science for Society’** projects.

The creation of the Facility will offer numerous opportunities for technology transfer to the SEE-states. In particular, this will be a great benefit for the SEE local industry since the procurement of the different components for the machine and beam lines (magnets, vacuum system, girders, beam lines, power supplies, control system, etc.) can be preferentially assigned to local industry. Moreover, the initiative will give rise to spin-offs not directly linked to the facility, but also trigger complementary technologies.

Thanks to the first financial support by the European Commission – Directorate General for Research and Innovation (EC DG RTD) the SEEIIST project is now entering into a Design Study Phase which will be hosted in the renowned research centers CERN and GSI. In the past, CERN has indeed rendered very valuable services to European science beyond its main task by offering help for the foundation of EMBO and ESO, not to mention the invaluable support given to the SESAME project. At GSI the first 440 patients were treated in Europe with this most modern method. The preparatory groups have just been set up. The central goal would be to push a next generation facility for tumour therapy and biomedical research with multi-ion sources, which would even be a benefit for Europe as a whole.

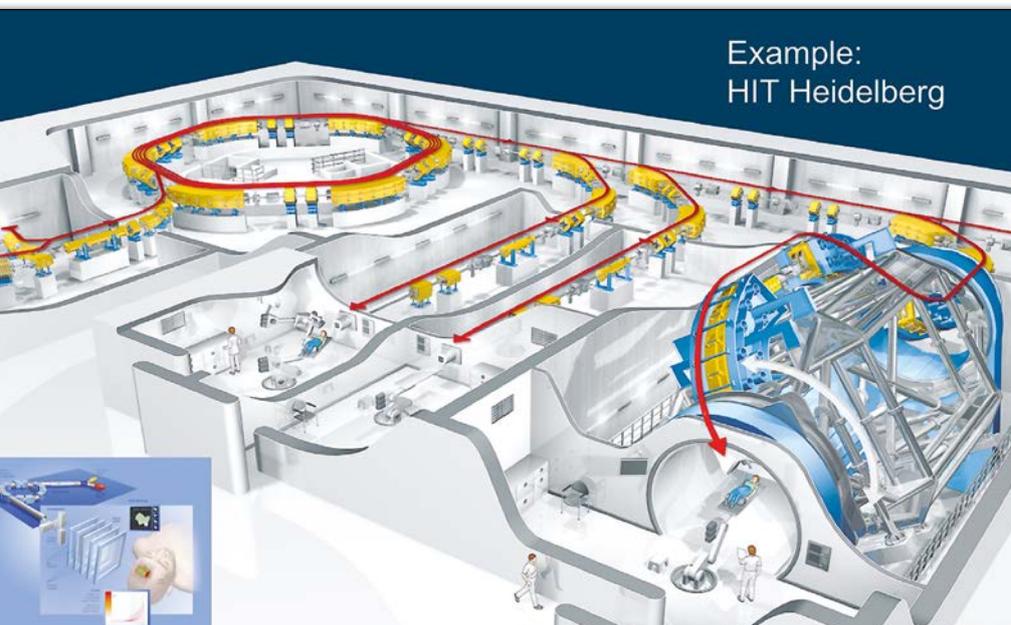
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**Sanja Damjanovic** made her Diploma in Physics at the University of Belgrade. She continued with PhD studies in 1999 at the Faculty of Physics and Astronomy, Ruprecht-Karls University Heidelberg, Germany, and received her Dr.rer.nat.

in Physics in 2002 with the Grade ‘Magna cum laude’. In 2006 she obtained a CERN Fellowship, an award-type position. Since 1999 embedded in international teams, she has ever since worked in two large International Organizations, at CERN in Geneva and at GSI-FAIR in Darmstadt, covering both basic and applied research in the field of high-energy nuclear physics. About 100 publications in refereed journals and conference proceedings. About 50 technical reports and numerous colloquia, seminar- and conference talks all around the world. In November 2016 she was appointed as Minister of Science in the Government of Montenegro.

▼ **FIG 2:**  
First Hadron Cancer Therapy Machine in Europe – HIT Heidelberg (left); The potential Member States of the South East Europe (right). at Poznan (right).



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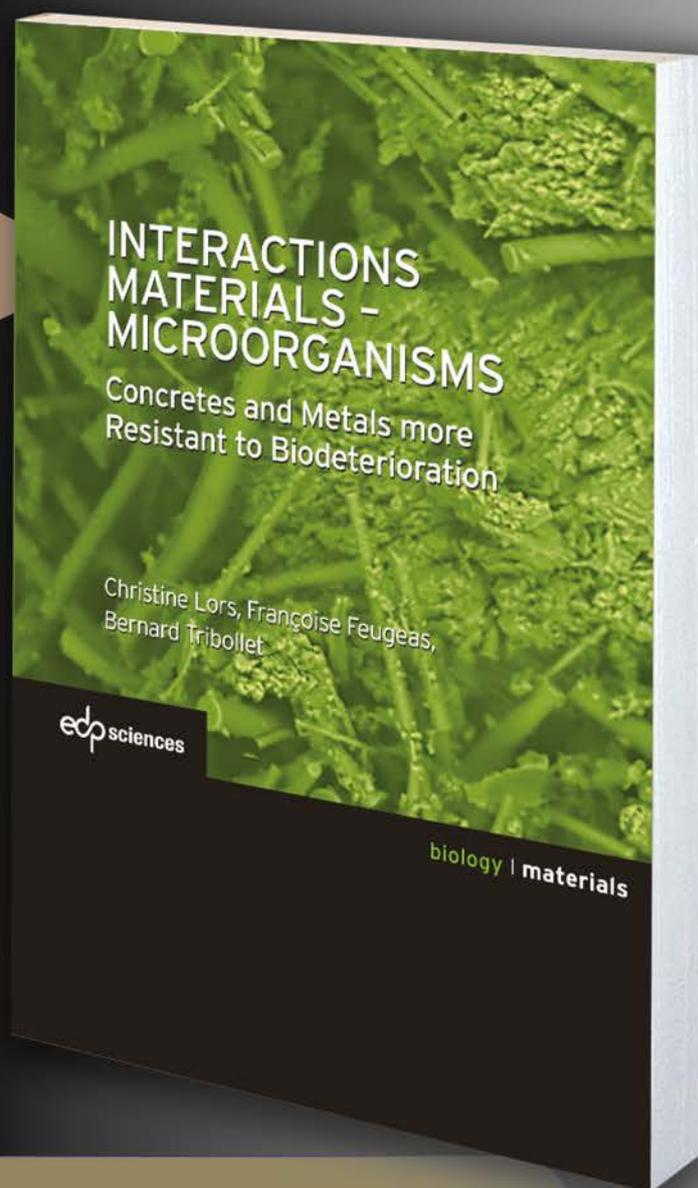
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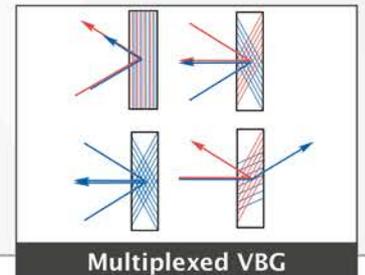
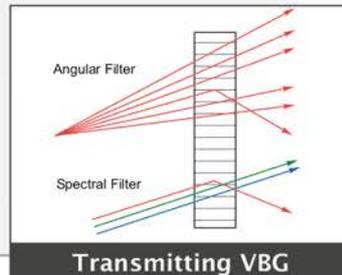
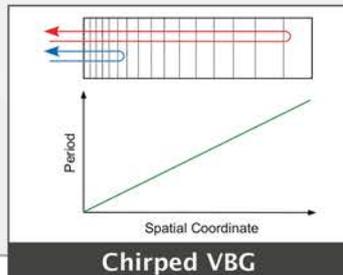
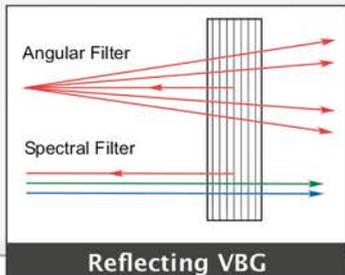
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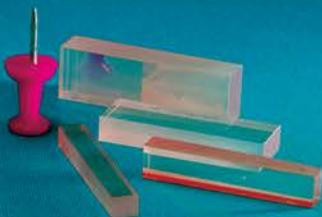
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