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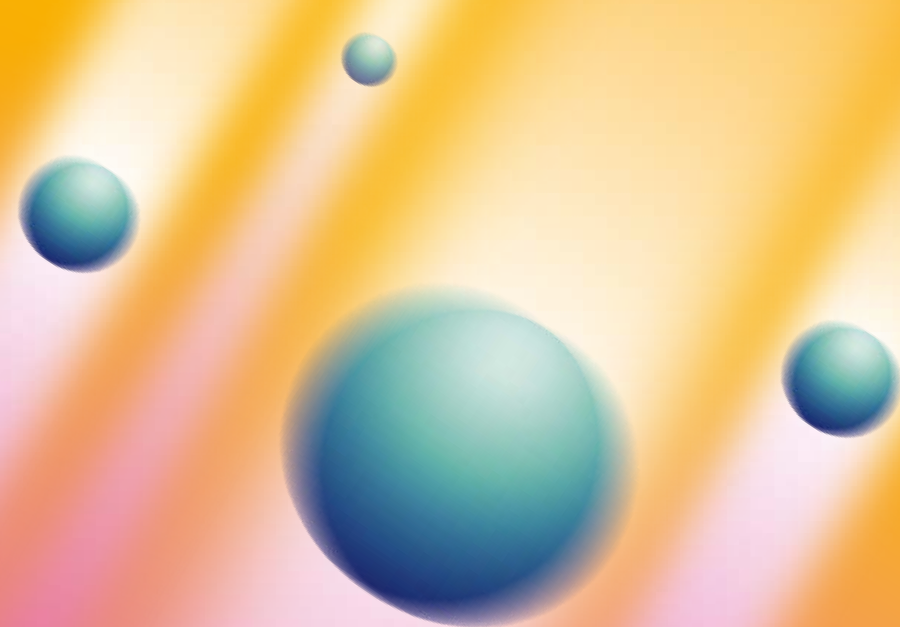
The quantum artists: researchers crafting the future

Interview
"Switzerland must continue to press ahead in quantum research"



The magazine of the Paul Scherrer Institute PSI

Quantum: the intricate shape of the future

Quantum research is probing the poetry of the infinitesimal – and revolutionising our world

PSI

Key topic

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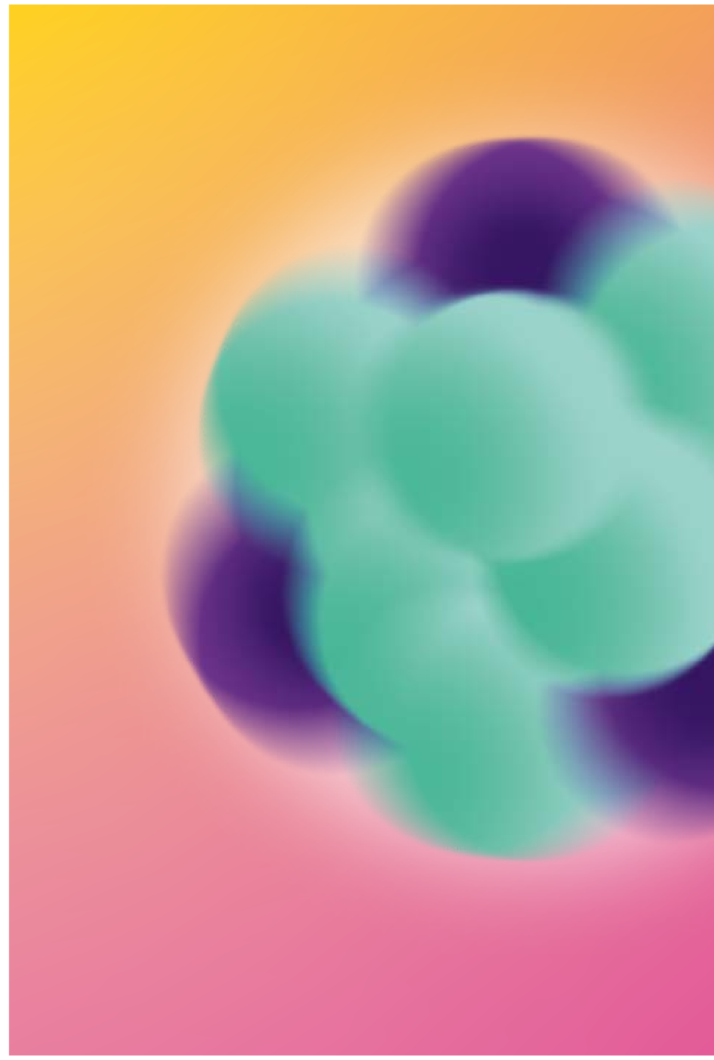

Background

The quantum artists

Capturing atoms with light beams or generating two opposing oscillations simultaneously is a special art. PSI researchers are becoming increasingly adept at it.

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Interview

"Switzerland must continue to press ahead in quantum research"

Heike Riel heads IBM's quantum research in Rüschlikon. In an interview, she talks about the importance of this field of study and the role played by Switzerland.

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The art of the quantum

Don't worry: If you think you'll never be able to grasp quantum science, you're in good company. Even researchers find quantum mechanics a bit challenging – although its discovery dates back a hundred years: in 1925, important scientific publications appeared that still form the foundation of this research field. In this magazine, we're taking this anniversary as an opportunity to make quantum science more accessible to you.

At the time, there was a lot that researchers were not able to interpret – but they accepted that, on the smallest scale, nature's behaviour is very different from what we experience in everyday life. And: with their new formulas, researchers were able to make calculations about the world of atoms that yielded reliable predictions. Perhaps quantum physics is like art – the practical impact is just as important as a detailed understanding.

Some aspects of quantum phenomena remain mysterious to this day; nevertheless, researchers can still make use of them. To do this, they use optical tweezers to position individual atoms so precisely that the calculated effects occur; or they deform a material made of extremely thin layers in such a way that its quantum nature brings forth highly useful properties. In this issue, we report on how this has led to products already in use today as well as what might yet come in the future.

Though our institute's quantum research may not yet be its main claim to fame, it does play a role in many areas of PSI research. The more closely researchers examine things – whether in materials for future technologies or when studying important molecules in the human organism – the more prominently quantum effects come to the fore.

That's why we have now dedicated a separate building on the PSI campus, additionally to the ETH-PSI Quantum Computing Hub, to fundamental quantum research on materials. You see me here in the nearly finished and still empty laboratory hall of the new QMMC: the Quantum Matter and Materials Center. Here, many research groups that were previously scattered across the PSI campus will be able to collaborate better than before, and to develop and utilise new instruments together.

And if the world of the smallest things doesn't impress you, join us for a look at one of the world's largest machines: the particle accelerator at CERN. Read how a PSI research group is helping to prepare for the next upgrade there, starting on page 22.

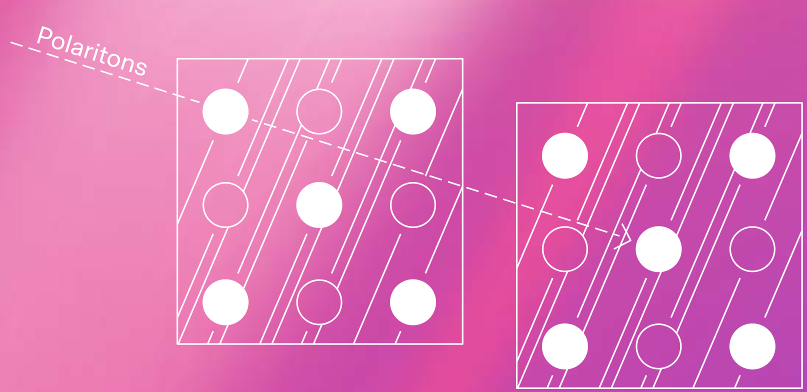
Finally, we'll treat you to a beer – at least on paper. Former PSI researcher Luc Van Loon runs a small but outstanding brewery. Our author didn't pass up the opportunity for a visit. I wouldn't have either.

Sincerely yours, Christian Rüegg, PSI Director

Quantum: the intricate shape of the future

The quantum world is mysterious. Yet researchers are gaining an ever better understanding of its curious rules. And using them to develop technologies that will change our lives.

Text: Bernd Müller



Computers without cables

Laser beams can be used to capture individual atoms and position them precisely (see large image). Wenchao Xu places different types of atoms in an ultrahigh-vacuum chamber and uses these atoms as qubits. As the number of qubits increases, even atoms that are far apart from each other need to be connected. This is where polaritons come into play. These quasiparticles have properties of both light and matter, making them ideal postmen for delivering quantum messages over long distances. Wenchao Xu wants to use them to connect remote individual atoms for modular quantum computation.

The quantum artists

Researchers at PSI are challenging our everyday experiences: they are creating new materials, constructing mosaics of precisely positioned atoms, getting electricity to flow without resistance – and even slowing down time in simulations. A glimpse into the laboratories where the future is being created.

Chapter 1: Slowing time and trapping ions

Cornelius Hempel uses quanta to perform calculations on quantum phenomena. While this sounds logical, it's actually highly complex. His latest coup: a quantum simulator that slows down time.

How nice it would be if one could slow down time. Looking in the mirror wouldn't reveal a new wrinkle every morning; and a wonderful holiday could be drawn out a little. Cornelius Hempel has relatively few wrinkles. However, this is probably because the physicist at the PSI Center for Photon Science is just 44 years old, rather than a result of the machine his team has built in a windowless laboratory – a seemingly chaotic jumble of cables, lenses and lasers. And yet: It slows down time – at least in complex calculations. The machine is a quantum computer based on an ion trap, and Hempel uses it to simulate ultrafast chemical reactions in slow motion. It cannot be used to prevent wrinkles.

Cornelius Hempel explains that his quantum simulator is actually an atomic clock. Both work with ions – that is, electrically charged atoms – captured in a trap, whose electrons are made to oscillate using lasers, much like a pendulum swinging back and forth in an old clock. The first atomic clocks, built in the 1950s, were driven by microwaves. They continue to form the basis of how we measure time, and their oscillations define the second – around 9.1 million oscillations correspond to one second. Atomic clocks achieve this with an accuracy of 16 decimal places, meaning they would be off by no more than about one second every 100 million years. Today's ion-based models are a thousand times more accurate. "Nothing else can be measured more accurately than time," says Hempel.

Hempel uses the atomic clock as a quantum simulator, a controllable quantum system that can replicate another quantum system – often a solid or a liquid. The behaviour of quantum systems is best calculated using quantum computers – Richard Feynman, winner of the Nobel Prize in physics, had already proposed this in 1982. For a long time, Feynman's concept lay dormant. The idea was not pursued further until the 1990s; the first prototype of a quantum computer based on an ion atomic clock was demonstrated in 1995.

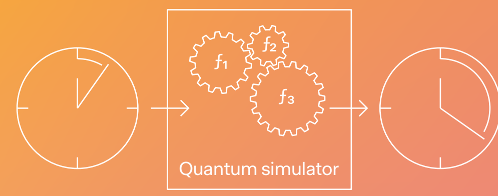
Atomic nuclei, vibrating naturally

Over the last decade, quantum computers have made such great progress that they are now ideally suited to serve as quantum simulators. This gives physicists a new and powerful tool they can use to calculate the behaviour of molecules – that is, groups of different atoms – right down to the quantum physical details. Even the fastest supercomputers often fall short here. But to obtain meaningful results, researchers have until now had to treat the atomic nuclei as though they were frozen in space; the supercomputer only calculates how the electrons move around the nuclei. However, this is unrealistic. "The atomic nuclei actually vibrate, and they should do so in the simulation," says Hempel. The quantum simulator is a promising approach because the nuclei vibrate naturally in their trap.

The disadvantage of a quantum simulator is that it cannot achieve the ultrafast pace of phenomena in the world of molecules and atoms. Instead, its speed corresponds to that of the underlying quantum system. This is where the "time-brake" comes in. It uses a mathematical model that matches the system being simulated to describe the behaviour of the ions in the experiment – but with a time-stretching factor of 100 billion. In fact, Hempel doesn't slow down the quantum system itself, but rather the way it is represented in the mathematical model.

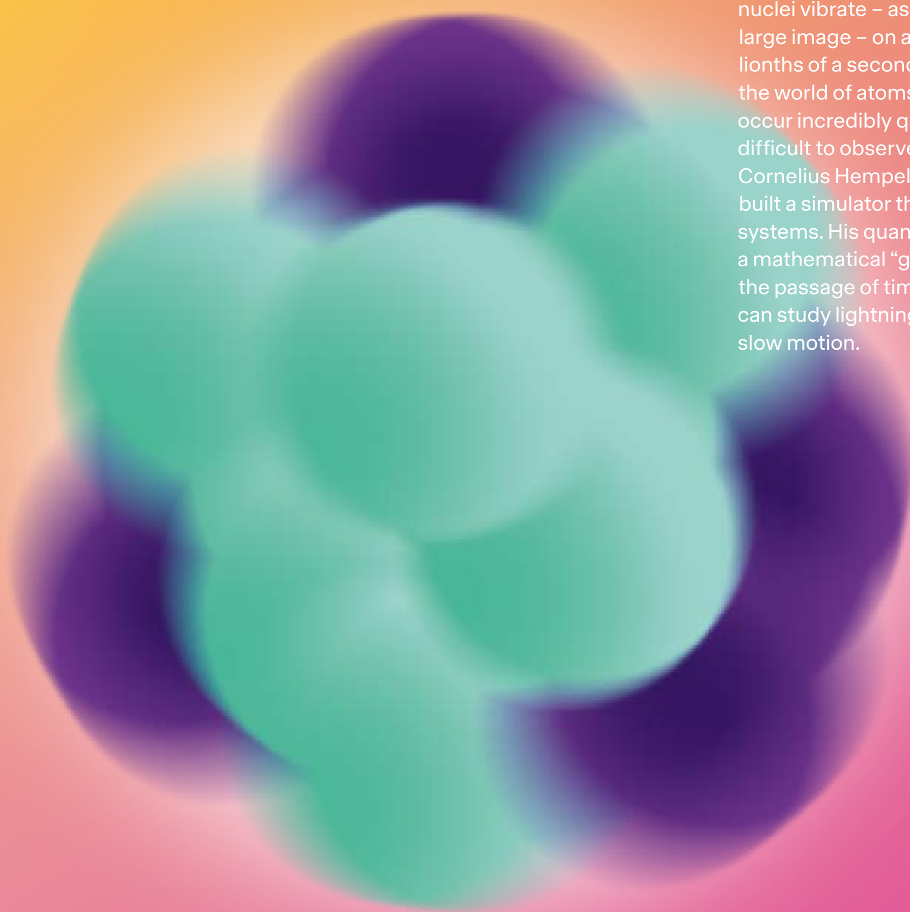
Lightning-fast information in the eye

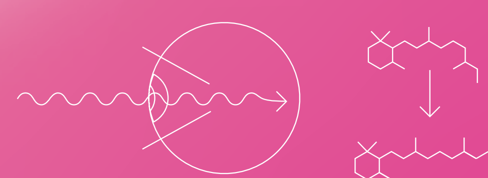
Ultrafast chemical reactions occur naturally in a wide variety of settings. They prevent us from constantly getting sunburnt by converting incoming ultraviolet



Slowing time

Extremely small and incredibly fast: Atomic nuclei vibrate – as indicated here in the large image – on a timescale of ten quadrillionths of a second. Many other processes in the world of atoms and molecules also occur incredibly quickly. This makes them difficult to observe in a laboratory setting. Cornelius Hempel has found a solution. He has built a simulator that mimics other quantum systems. His quantum simulator contains a mathematical "gearbox" that stretches out the passage of time. That way, Hempel can study lightning-fast processes as if in slow motion.





Rapid retinal

Retinal is a molecule found in the retina of the eye. When light strikes it, the molecule changes its shape, and a signal is sent to the brain. This takes just under half a trillionth of a second. Cornelius Hempel mimics this process with his quantum simulator. The extremely high temporal resolution he achieves complements the experimental investigations of other PSI researchers.

radiation that reaches our genes into heat before it can cause damage. Very rapid chemical reactions also occur in the retina, for example. The molecule retinal translates incoming light into information, which the optic nerve then transmits to the brain. When a light particle – known as a photon – strikes it, the curved molecule straightens out at lightning speed, stimulating the optic nerve. Other PSI research groups are investigating this process experimentally using the X-ray free-electron laser SwissFEL. Retinal reacts within only around 400 femtoseconds, or just under half a trillionth of a second. In Hempel's quantum simulator, however, the calculation takes place at a leisurely pace, in a matter of milliseconds. This has the advantage that the researcher can study exactly what happens when the molecule is deformed and how the atoms interact.

A quantum simulator usually works as an analogue system; a quantum computer, on the other hand, is digital. The qubits of a quantum computer know the binary states 0 and 1, on which classical computing is based – but with a difference. Qubits can exist in both states at the same time, to different degrees. This greatly increases their computing power for certain tasks.

Digital fodder for analogue quantum computers

What if you could combine a quantum simulator and a quantum computer, that is, the analogue and digital modes? The result would be a quantum simulator that could be fed with digital information. Andreas Elben and Andreas Läuchli, members of the PSI Center for Scientific Computing, Theory and Data, have described how to combine the best of both worlds in a groundbreaking publication in *Nature*, one of the most renowned scientific journals. Working alongside researchers from Google and universities in five countries, they have demonstrated that just 69 qubits on a Google quantum computer can be used to calculate quantum dynamic processes such as heat propagation in a liquid, for example when two substances at different temperatures are mixed in a chemical reaction.

This concept paves the way for a universal quantum simulator and is to be used in many different areas of physics. Cornelius Hempel's ion traps are also suitable for creating a universal quantum simulator.

Sluggish sparrows on a power line

Hempel has arranged several dozen ions in a chamber, lining them up like sparrows on a power line. To make them perform calculations, he needs to stimulate them from the outside with a laser beam – not a problem with this number. However, if the aim is to host millions of qubits on a single chip, the lasers will have to be integrated on the chip in such a way that they can be switched on and off individually – a challenge in integrated photonics. While this technology already exists in data centres today, the integrated lasers used there are too large and emit light at wavelengths in the deep infrared range; quantum computers require visible light. "That's why we are developing these technologies ourselves at PSI," says Cornelius Hempel. Perhaps one day this will lead to hybrid processors that combine the atoms and lasers of a quantum computer with conventional silicon electronics.

These technologies are still some way from commercial application. There are other groups at PSI working on closing this gap, including Kirsten Moselund's team in the Laboratory for Nano- and Quantum Technologies at the PSI Center for Photon Science.

And many industries – including electronics, measurement technology, and photonics – are already seeing benefits from the developments surrounding quantum computers. "A great deal of research at PSI focuses on phenomena that we would very much like to understand down to the level of quantum physics," Cornelius Hempel emphasises. "And quantum phenomena are present in many current and future products, to which our work can then make a crucial contribution."

"Quantum phenomena are present in many current and future products to which our work can make a crucial contribution."

Cornelius Hempel, researcher at the PSI Center for Photon Science

Chapter 2: Terbium duet and other quantum art

To create more stable qubits, PSI researchers make terbium ions perform in pairs. Elsewhere, they are using optical tweezers to position atoms with high precision.

Wenchao Xu, researcher at the PSI Center for Photon Science, positions atoms with laser beams. Using such "optical tweezers", she wants to arrange up to 5,000 atoms with accuracy.

In the fairytale, Cinderella enlists birds to help her sort lentils: "The good ones go into the pot, the bad ones into your crop," she tells them. When it comes to quantum computers, too, the good must be separated from the bad – at the level of atoms and their electrically charged siblings, the ions. For researchers, the "good" are the qubits: atoms or ions, for example, capable of performing calculations in a quantum computer. Qubits are usually very sensitive; even the smallest mechanical or magnetic disturbance from outside can cause the so-called coherence to collapse in a fraction of a second. Then the qubits are thrown out of sync, and the quantum information is lost. They become "bad" qubits, a hindrance to a quantum computer's calculations.

In current quantum computers, qubits are relatively far apart, so they don't interfere with each other. While this works well with 50 or 100 qubits, it becomes problematic when you envision future quantum computers with many millions of qubits that need to be packed together very densely, like the bits on today's computer chips. They would be likely to interfere with each other, turning "good ones" into "bad ones."

Simon Gerber and Gabriel Aeppli at the PSI Center for Photon Science know a way to keep even densely packed qubits in the "good" pot for significantly longer. Their terbium ion qubits are embedded in the atomic lattice of yttrium lithium fluoride crystals. The astonishing result of this is that the qubits produced by the terbium ions are more stable than expected, in other words their coherence is much greater.

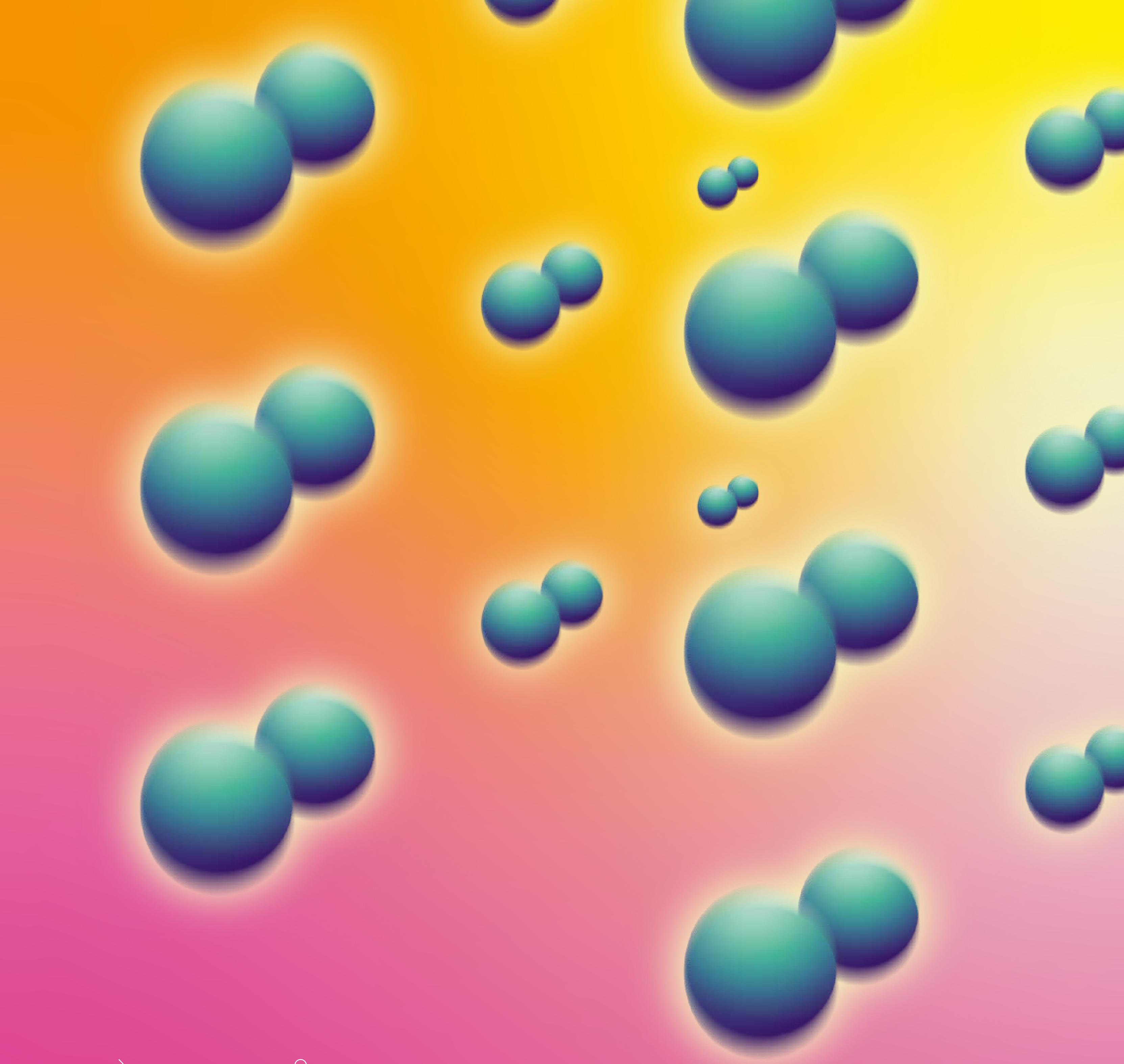
"The trick is that the qubit states are now stored in the interaction of two ions rather than individual ions, as is customary," explains Gerber. "These ion pairs form naturally when you add a lot of terbium to the crystal." The advantage is that ion pair qubits communicate at a very specific frequency that cannot be disrupted by individual terbium ions or other atoms in the crystal. It's like using a new radio frequency far from those used by existing transmitters. The old frequencies don't cause interference. In terms of the qubits, this means that you can communicate with them unimpeded, and their coherence is maintained many times longer. This makes the PSI approach extremely interesting for the construction of future quantum computers.

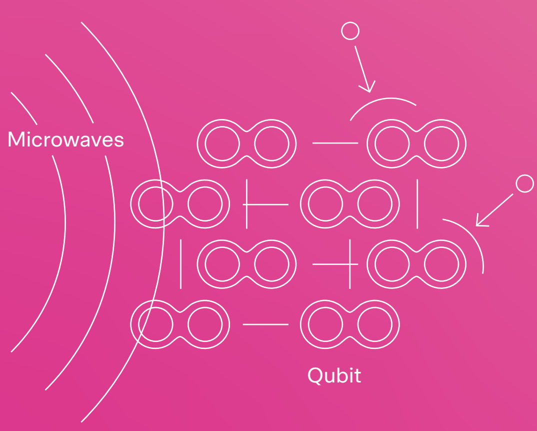
A protective shield made of microwaves

But things can get even better. Another threat to terbium ion qubits is external magnetic disturbances. Irradiating them with microwaves, however, provides a protective shield. The paired qubits then have a lifetime up to a hundred times longer than qubits made of individual, non-irradiated ions. "With the right material, the coherence could last even longer," says Gabriel Aeppli, head of the PSI Center for Photon Science. The team now wants to use their knowledge of this phenomenon to further optimise the setup.

The experiments, published last year in the journal *Nature Physics*, open up an intriguing new avenue for building quantum computers. However, simply scattering terbium ions into a crystal lattice won't be enough. "The trend is towards a quasi-surgical placement of atoms or ions," says Aeppli.

Wenchao Xu is familiar with the arrangement of individual atoms. She too is a scientist at the PSI Center for Photon Science. However, her atoms are not located in a solid, but float in the vacuum inside a compact chamber. Xu aims at positioning up to 5,000 atoms with high precision using an array of focused laser beams. "We refer to this technique as optical tweezers. Each laser beam can capture and position a single atom," Xu explains. Her team uses the individual atoms as qubits and, from many atoms positioned in this way, builds quantum processors.





Protective shield for qubits

The biggest obstacle to building a quantum computer is that qubits, which are made up of atoms or ions, for example, are extremely sensitive and can be thrown out of sync by the slightest disturbance. However, some ions can form pairs, which makes them more resistant. Irradiating them with microwaves increases their stability even further. Simon Gerber's team is investigating these promising qubits.

Hybrids of light and matter

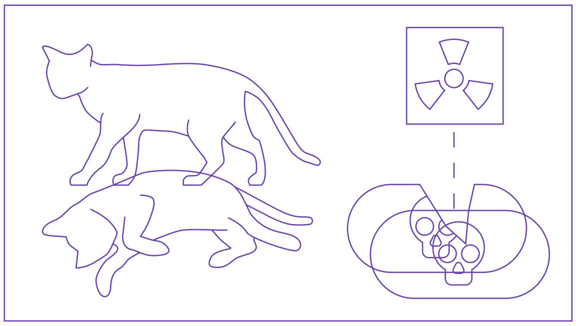
Xu is also investigating possible ways to set up connections between quantum systems. For this purpose, she uses so-called polaritons. These are quasiparticles that simultaneously possess the properties of light and matter. They could potentially serve as interfaces between atomic qubits and light, carrying quantum information over longer distances. Using polaritons to connect multiple quantum processors to each other, larger quantum computers could become a reality.

Polaritons are also of interest to Dominik Sidler, a theoretical physicist at the PSI Center for Scientific Computing, Theory and Data. He studies the quasiparticles not in the laboratory, but in computer simulations. He is investigating the strong coupling of light with matter. When molecules are locked in a tiny hall of mirrors and light is allowed to bounce back and forth, the light can alter the molecular structure and thus its chemical properties as well. The remarkable thing is that no external light is needed. The quantum effect occurs even in absolute darkness. However, why does this alter the chemical properties? This is still largely unknown, because current physical models don't actually allow for it. Here, too, polaritons might be involved.

Sidler is trying to uncover the secrets of polaritonic chemistry. If successful, his work could for example lead to more energy-efficient ways of producing the active ingredients for drugs, because the light traps would allow the chemical structures to be selectively modified.

Cat qubits

While researchers like Simon Gerber and Wenchao Xu use use what nature provides as the smallest building blocks for their qubits – atoms and ions – Alexander Grimm takes a different approach: he creates qubits artificially. To do so, he uses so-called microwave resonators, in which an electrical signal can oscillate back and forth like a pendulum. Grimm's research group is able to precisely control the oscillation state in these resonators. What's more, at minus 273 degrees Celsius, Grimm can create a quantum mechanical superposition – that's when two opposing oscillations occur simultaneously. It's as if a classical pendulum were swinging in opposite directions at the same time. "In this way, we create in the laboratory something like Schrödinger's cat," says Grimm, referring to Erwin Schrödinger's famous thought experiment. The advantage of these cat qubits is that the two opposing states are resistant to disturbances, so Grimm's qubits naturally stay longer in Cinderella's "good" pot.



Schrödinger's cat

In this 1935 thought experiment, a fictional cat is locked in a box with a capsule containing a lethal poison. There is exactly a 50 percent probability that a certain nuclear reaction will occur, releasing the poison. According to quantum mechanics, both atomic states exist simultaneously as long as the outcome is not measured. The physicist Erwin Schrödinger asked whether the cat could, therefore, be both dead and alive at the same time. This seems to contradict our everyday experience, which is governed by classical physics. This does however not disprove quantum physics.

The ideal place for quantum research

The many different approaches pursued in quantum research are particularly successful when researchers from different fields work together. "Every discipline has its own language, its formalisms. So it's important that we transcend our own disciplinary boundaries and explore new possibilities," says Dominik Sidler. "PSI is the ideal place for this – also thanks to our close cooperation with the universities in the ETH Domain and our many contacts with leading international institutions."

"We mutually enrich each other's research," agrees Simon Gerber. The experiment with pairs of terbium ions, for example, could also lead to the development of new types of sensors. Essentially, understanding what is happening at the levels of atoms and electrons, large "microscopes" are needed. "The large research facilities at PSI, which are unique in the world, can help us understand the properties of materials," says Gerber, "thus opening up a multitude of new possible applications."

Chapter 3: Atoms under pressure

Zurab Guguchia puts pressure on matter – and in doing so, creates exciting quantum effects such as superconductivity at more easily achievable temperatures.

Materials scientists aren't exactly squeamish. They clamp materials tightly and push or pull at them with great force until the samples break or shatter. Things aren't quite so rough in Zurab Guguchia's lab, though. The physicist at the PSI Center for Neutron and Muon Sciences isn't trying to destroy anything, but rather to create something new. For example, exotic substances that conduct electricity without any losses, even at high temperatures, or that exhibit novel magnetic and electronic properties. If his experiments are successful, they could not only provide new insights in quantum physics but also open doors to practical applications – such as energy-efficient power grids or electric motors that don't require rare-earth magnets. These metals aren't exactly rare, but mining them is complex and expensive.

The sample that Guguchia is currently examining at the Laboratory for Muon Spin Spectroscopy is invisible to lab visitors. The small metal fragment is hidden in a tube, immersed in an oily liquid that exerts gentle, all-round pressure. As the hydrostatic pressure gradually increases, the measuring instruments display surprising values. Suddenly, superconductivity sets in: electric current flows without any resistance – triggered solely by the pressure and without the need for extreme cooling of the sample, as is normally required for superconductivity.

Guguchia discovers fascinating effects in his data almost every week. He regularly publishes in prestigious scientific journals, including a 2022 article in *Nature* – a great honour for any researcher. In conversation, he hints that further publications are already in the works.

His latest study involves a material with a layered structure, like puff pastry, where each layer is only one atom thick. Place the sample on a lab bench, and nothing happens. But if you clamp it in a movable frame and pull gently, the layers stretch and move closer together – just like pastry dough being rolled out. Alternatively, you can place the sample in an oil-filled tube where the hydrostatic pressure acts on it evenly from all sides. If all the parameters are right, something magical happens: the electrons – negatively charged particles that orbit atomic nuclei – begin to sense the electrons in neighbouring layers. This creates so-called quantum phases: the material loses its electrical resistance and becomes superconducting, or develops magnetic properties, or forms a charge-ordered structure in which the charge carriers arrange themselves in regular patterns. In quantum materials, these three ordered states often coexist and interact in complex ways.

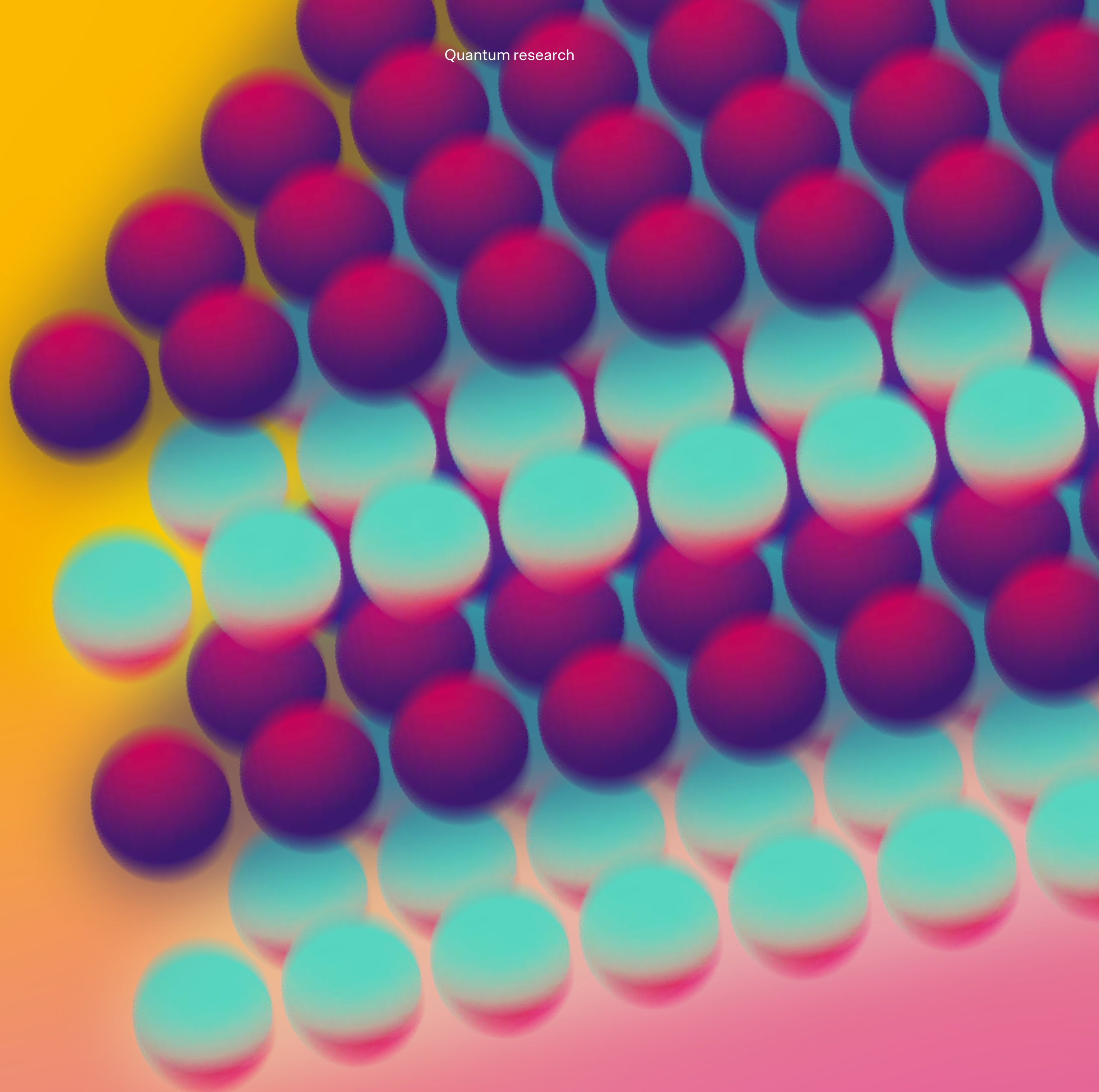
"My main interest is to understand the fundamental mechanisms behind unusual quantum phenomena."

Zurab Guguchia, researcher at the PSI Center for Neutron and Muon Sciences

Conflict of the quantum phases

Physicists know of many different quantum phases such as these, each producing distinct types of electron interactions. If the sample is stretched or compressed, it can also exhibit properties contrary to the expected results. Therefore, Guguchia precisely adjusts the forces in the compression or tension device to suppress undesirable phases and enhance desirable ones, such as superconductivity. The desired effect only occurs when the atomic layers are distorted in a very specific direction. For example, Guguchia discovered that applying a tensile force to cuprates – Nobel Prize-winning high-temperature superconductors – can increase their superconducting temperature fivefold. These findings underscore the potential of such mechanical distortion. The research has been published in two highly regarded journals.

Guguchia envisions a material that can be switched into various desired phases – or even modulated continuously – by external forces. It could serve



Under pressure

Some materials have a layered structure, like puff pastry – each layer having the thickness of only a single atom. If these layers are squeezed together or pulled, the materials develop astonishing properties: current flows without resistance, or the material develops magnetic properties. In his experiments, Zurab Guguchia investigates materials whose properties can be modified in specific ways by external forces.

as a kind of switch that shifts from zero resistance (superconducting) to a metal's normal resistance. In combination with other materials, products with novel technical properties are conceivable – such as electric motors that do not require rare-earth magnets.

Atomic bamboo baskets

Guguchia is continuing his experiments with hydrostatic pressure and directed tension. In the scientific community, however, he is known worldwide for another major discovery – one that has earned him invitations to leading international conferences: kagome. An Internet search for this term will produce images of traditional Japanese woven bamboo baskets. In the quantum world, there are atomic lattices that replicate this pattern of hexagons surrounded by triangles at each edge, which in turn are connected to other hexagons – in an endlessly repeating structure.

Scientists have long suspected that flat, two-dimensional atomic lattices can exhibit charge ordering. This arises from the collective behaviour of the electrons, through spontaneous currents, without external excitation. Guguchia was the first to discover this experimentally in the laboratory, in a kagome lattice made of potassium, vanadium, and antimony atoms. The breakthrough came thanks to the powerful SμS muon source at PSI. In the experiment, a muon – an electrically charged elementary particle 200 times heavier than an electron – serves as a highly sensitive microscopic measuring instrument. It is implanted into the kagome lattice and observed as it decays. This provides information about the local magnetic field and thus about the spontaneous currents flowing in the ring of six atoms.

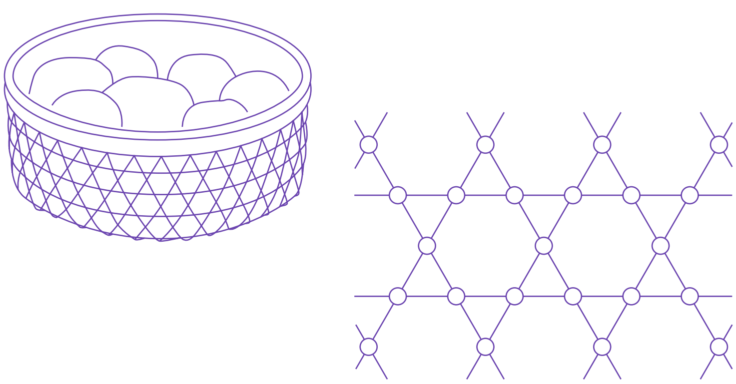
While a suitable material typically needs to be cooled to around minus 240 degrees Celsius to become superconducting, in the kagome lattice this effect already occurs at around minus 190 degrees Celsius – a temperature that can be achieved by relatively inexpensive cooling with liquid nitrogen. Researchers also suspect that such spontaneous currents could exist in cuprates – the high-temperature superconductors whose discovery was awarded the Nobel Prize in Physics in 1987. There is growing hope that applying the kagome architecture to these materials could further increase their critical temperature.

Wanted: Room-temperature superconductors

This hope has intensified in recent months. Guguchia recently discovered charge ordering in a Kagome lattice at temperatures up to 527 degrees Celsius – a finding published in the renowned journal *Advanced Materials*. While superconductivity in the same material typically occurs at low temperatures, Guguchia's pressure experiments showed that it does not follow conventional rules. This raises a key question: Could the charge ordering be suppressed at high temperatures? And might this reveal a state near room temperature in which current flows without resistance and without cooling?

As someone engaged in fundamental research, Guguchia remains modest: "This quantum system is very promising." But the implications are far-reaching. A superconductor that works at room temperature would revolutionise the energy landscape: cables with zero electrical resistance could potentially save 40 percent of global energy consumption.

"My main interest is to understand the fundamental mechanisms behind unusual quantum phenomena and learn how they can be optimised," says Zurab Guguchia. "With its unique combination of large research facilities and strong theoretical and computational research groups, PSI is the perfect environment to combine theoretical and applied research." ●



Atoms in a pattern

Kagome is a pattern used in traditional Japanese woven baskets. The characteristic kagome pattern of triangles and hexagons is also found in the arrangement of atoms that Zurab Guguchia is studying. By subjecting his kagome lattice to pressure, he achieved superconductivity at a higher temperature than had ever been demonstrated in such systems before. At the same time, an unusual form of magnetism emerged. Guguchia is looking for ways to one day achieve such effects even at or above room temperature.

“Switzerland must continue to press ahead in quantum research”

Heike Riel is an IBM Fellow based in Rüschlikon and heads the company’s quantum research in Europe. With her team, the physicist is laying the foundations for future computers that will be unimaginably fast and energy-efficient.

Researcher, visionary, pioneering thinker: Heike Riel is developing the computer technology of tomorrow at IBM in Rüschlikon.

You are an IBM Fellow, a prominent position within the company that few achieve. What is your role?

As an IBM Fellow, I give impetus to the company’s strategy and provide critical advice to management. In particular, it is my responsibility to identify and advance innovative technical projects that will lead to technological breakthroughs relevant to the future of computing. We are working on the questions: what is the future of computing, and how can we further increase performance and energy efficiency? That’s why we are developing quantum computers and algorithms and also exploring new computing systems for artificial intelligence, as promising candidates for the next generation of computer technologies.

Does that mean quantum physics is finding its way into computer technology?

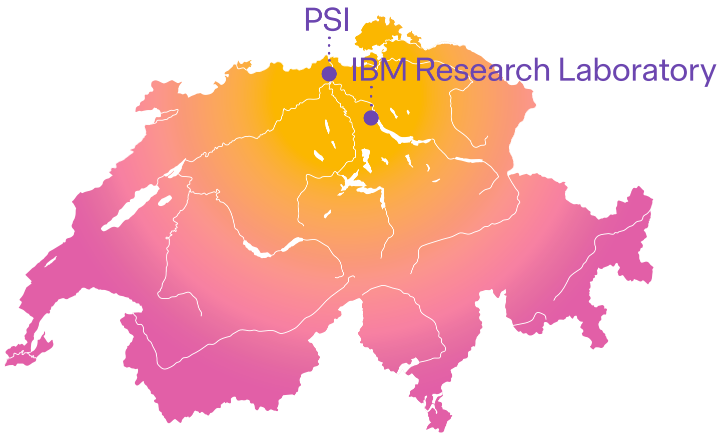
Quantum physics has been in use for a long time. For example, tunnel diodes, which were already invented in 1957, are now commonplace electronic components. There are many other technologies based on quantum physics. The laser, invented in 1960, has also become indispensable. In today’s second quantum revolution, attempts are being made to reach the next technological level by controlling individual quantum states – such as superposition and entanglement. We are particularly interested in quantum computers, which have the potential to solve computational problems that can’t be solved classically. A lot of progress has been made in quantum computing in recent years, so that scalable, error-tolerant quantum computers with 200 logical qubits are on our roadmap for 2029.

Will classical computers become obsolete?

No. Quantum computers are not a replacement for classical computers; they are complementary. For the foreseeable future, we will continue to write e-mails and surf the Internet on classical computers. Quantum computers will solve new tasks; that’s what fascinates me about them. One example is our understanding of quantum physics itself: Quantum systems are much easier to simulate on quantum computers because they obey the same physical laws. Remarkable progress has been made in this area in recent years. In particular, through clever use of the synergies between quantum computers and high-performance computers, and through error reduction, it is hoped that a quantum advantage will be achieved within the next two years.

There’s another strength of quantum computers that poses a threat to current encryption methods: Quantum computers can break down very large numbers into their prime factors and thus crack encryption codes. How do you intend to prevent this from being exploited for criminal purposes?

No classical computer can factorise large numbers into primes, which is why this is the basis of today’s encryption technology. However, an error-tolerant quantum computer that is large enough could do



Not just geographically close: PSI and IBM's research laboratory in Rüschlikon share a long history of joint projects – and a dynamic exchange of scientists in both directions.

it. The mathematician Peter Shor demonstrated this theoretically in 1994. We are preparing for this. The US standards authority NIST recommends three new encryption algorithms that should, to the best of our current knowledge, be unbreakable even by the most powerful quantum computers. Our team here in Rüschlikon has made significant contributions to these algorithms.

In 2022, you co-signed an open letter from renowned researchers calling for more funding for quantum technologies in Switzerland. How do you see Switzerland's position now?

Quantum technologies are still in their infancy worldwide; the potential for innovation is enormous, as is the dynamic nature of their development. Switzerland faces tough international competition. Recently, there was a weak phase after the European Union excluded Switzerland from funding for research projects on quantum technologies. As a result, we became less attractive to young researchers seeking European Research Council funding, and start-ups relocated, primarily to Germany, which had invested heavily in this area. The number of Swiss patents in quantum technologies declined during this period. Switzerland has now recovered, thanks in part to funds established by PSI and ETH. Furthermore, Swiss researchers can now once again participate in EU calls for proposals. Switzerland continues to be in a very good position thanks to its strong innovation culture and established companies in the quantum technology supply chain. But we must not let up.

How would you characterise the collaboration between IBM in Rüschlikon and PSI?

PSI's roots lie in the operation of large research facilities, which we IBM researchers also use from time to time. There is also a fruitful exchange of doctoral candidates and postdoctoral researchers. Finally, we work very closely with Kirsten Moselund, the head of the Laboratory for Nano and Quantum Technologies at PSI. She previously worked with us in Rüschlikon for 14 years and led a large research group in my department. Together with her current PSI team, we are working on innovative projects that combine classical silicon technology with photonics and take advantage of new physical effects.

Please tell us what concepts for future computers you are currently working on.

For example, we are working on new architectures for artificial intelligence that use only 16, 8, or 4 bits instead of the current 64 bits. These chips deliver the same computing results and the same accuracy, but more rapidly and with lower energy consumption. Another exciting approach is IBM's NorthPole chip, whose memory and processing units are closely integrated, thus reducing the energy required to transport data. This architecture, mimicking the brain, saves time and energy, especially in AI applications, where large amounts of data must be constantly shifted back and forth between memory and logic. However, this is only an intermediate step towards a new type of analogue processor, in which the computing operations are performed directly in the memory cell, which offers enormous advantages in terms of energy efficiency and speed. Processors with lower bit counts are already in our products, and we already have the first functioning prototypes of in-memory processors that demonstrate that it is possible to achieve a significant advantage in energy efficiency and computing power. ●

Beyond lithium technologies

Sarbajit Banerjee is the head of the Battery Science Laboratory at the PSI Center for Energy and Environmental Sciences. Here he does research on fundamental processes in various types of rechargeable batteries. He uses the latest analytical techniques to investigate redox reactions, which occur when electrons are exchanged between two reacting agents during the storage and release of energy. Banerjee's research is contributing to the development and further improvement of new battery materials, working towards a sustainable energy future that goes beyond existing lithium technologies.

Daily life & Research Oxidation

Everyday life is full of phenomena that also play an important role in research. One example is oxidation.

Text: Brigitte Osterath

Daily life

From iron to rust

Oxygen is vital for human life. Without this colourless, odourless gas, we would suffocate. But oxygen is also quite aggressive: it reacts readily and rapidly with other substances. Oxygen molecules act as electron thieves, snatching electrons from other elements and thereby initiating further chemical reactions. Scientists refer to this as oxidation.

Oxygen is particularly eager to react with base metals like iron, especially in the presence of water. This produces iron hydroxide, which is then converted into iron oxide. The result of this chemical reaction is rust. This reddish-brown compound of iron and oxygen forms a porous, brittle layer on the metal, which flakes off over time, exposing new iron, which then again reacts with oxygen. Thus the destruction of the material progresses continuously. Even a large ship made of iron will gradually disintegrate and literally crumble away – due to oxidation.

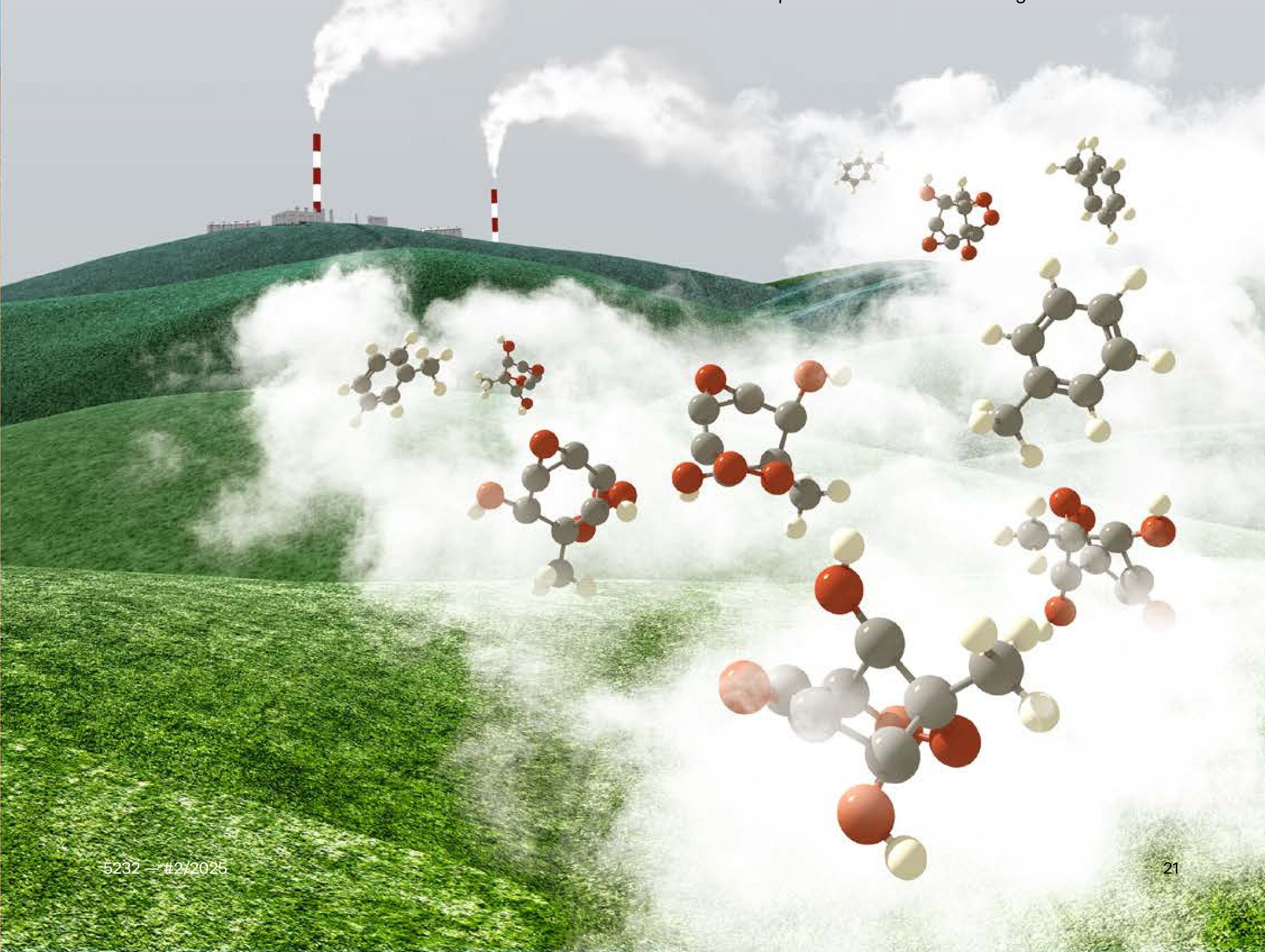
Research

From gases to particulates

It's not only iron that reacts with oxygen in the air. Gaseous substances also form new compounds through oxidation. And under certain circumstances, these particulates can be harmful to human health.

PSI researchers are investigating oxidation reactions in Earth's atmosphere to understand which substances are produced. They recently discovered that harmful particulates gradually form when oxygen reacts with gases such as toluene or benzene. These so-called precursor gases can originate from car exhausts and industrial emissions, for example. Once in the air, they undergo a cascade of oxidation reactions and eventually form solid particles: particulate matter.

The researchers' findings indicate that reducing direct particulate emissions from factories and vehicles, for example by using particle filters, is not enough. The precursor gases from which harmful particulates form must be regulated as well.



One thousand modules for CERN

At CERN near Geneva, tiny particles with extremely high energies are blasted at each other to answer big questions about the universe. The detectors that observe the collisions of these particles require regular upgrades. Lea Caminada and her High Energy Particle Physics research group at PSI play an important role in this quest.

In the stairwell of Park Innovaare, Lea Caminada, head of the High Energy Particle Physics group at the PSI Center for Neutron and Muon Sciences, is in conversation with Wolfram Erdmann, project leader of the Europe-wide consortium, which is building a significant part of the next CMS detector at CERN.

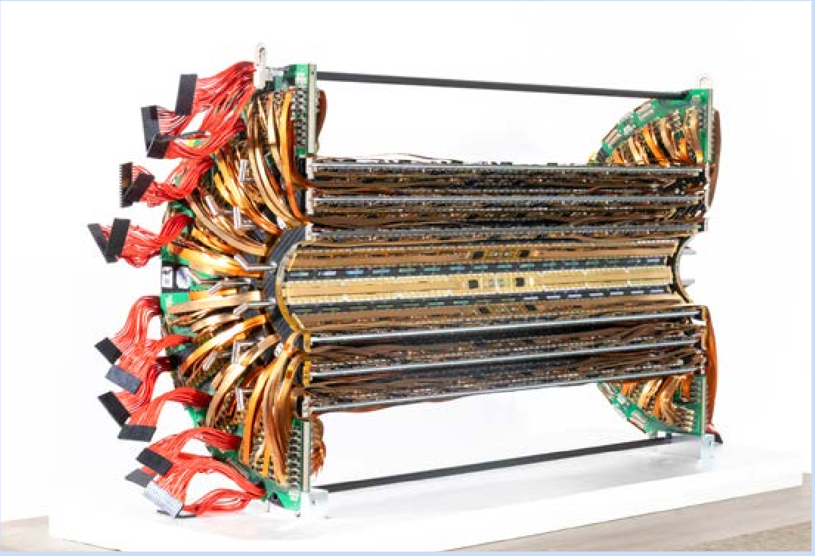
Text: Laura Hennemann

In a spacious laboratory on the third floor of a new building next to the Paul Scherrer Institute stands one half of the detector that traced the Higgs boson. This elementary particle, sought after for decades, was experimentally confirmed at CERN in 2012 – making history in particle physics.

The legendary particle was discovered using CERN's Large Hadron Collider (LHC) – a 27-kilometre-long underground particle accelerator. In the LHC tunnel, highly accelerated protons are fired at each other so that the decay products of these explosive particle collisions can be measured. The LHC continues to be used to answer questions about the fundamental physics of our universe. And it must keep up with the times: "The giant detectors need to be upgraded every few years," explains Lea Caminada, head of the High Energy Particle Physics group at the PSI Center for Neutron and Muon Sciences. "Among other things, this is because the high-energy particles that the detectors are designed to register inevitably damage their electronics over the years," the physicist explains.

To precisely measure the tiny particles, colossal instruments are needed: Four giant detectors are in operation at the LHC. One of them is called Compact Muon Solenoid, or CMS for short. Built in onion-like layers, this detector has an overall diameter of 15 metres. Lea Caminada has been working on the construction of the CMS detector and the experimental results it delivers practically since its inception.

The innermost part of CMS, known as the barrel pixel detector, is shaped like a slightly oversized Swiss roll. About 50 centimetres long, it consists of three layers of gold-gleaming electronics and a profusion of cables. It was originally developed and built at PSI, where Lea Caminada, then a doctoral candidate, was already involved. In 2017, this first barrel pixel detector was dismantled and replaced by a four-layer successor, also designed and partly built by Caminada's group. The original cylinder detector was split lengthwise into its two halves; one is now kept as an exhibit in Caminada's laboratory at the newly built Switzerland Innovation Park Innovaare, located directly adjacent to PSI.



The original barrel pixel detector of the CMS experiment at CERN. After being decommissioned, one half is now kept in Caminada's laboratory at the Switzerland Innovation Park Innovaare, right next to the Paul Scherrer Institute PSI.

CMS will remain in use in its current configuration until mid-2026, when a major upgrade of the entire LHC is set to begin. This will further increase the number of particle collisions, while at the same time providing an opportunity to replace many of the detectors' components with new, technologically improved parts.

End-caps to cover the blind spot

The LHC is scheduled to start up again as the High-Luminosity LHC in 2030. Many research groups around the world are currently working on individual new components of the CMS detector that will be installed during the renovation phase from 2027 to 2030. This time, rather than being responsible for the next barrel pixel detector, Caminada's group is working on disc-shaped components that will be mounted vertically in front of and behind the barrel detector.

"These discs form what we call the tracker end-cap detector," Caminada explains. "This will be a completely new part of the CMS detector. With it, we will be able to follow particle tracks that lie in the blind spot of the current detector." Different particle decays that could arise from proton-proton collisions in the LHC are expected to occur in different solid angles. If you're seeking new physics, you have to look where no one has been able to look before.

Each of the 16 circular discs that make up the tracker end-cap detector has a diameter of 50 centimetres, and each will be populated with silicon detector modules on both front and back.

"To thoroughly cover all these surfaces, we will need around 2,000 identically constructed detector modules," Caminada explains. These rectangular modules are smaller than the palm of your hand. They are highly complex electronic components that must be manufactured with extreme precision to operate reliably. "After the upgrade, the entire detector will remain in operation for several years – and we won't be able to remove or repair anything during this time." It's like sending a probe into space – during operation, you lose all physical access to the components. And every small probability of failure that you accept for a single component is multiplied by a factor of 2,000 for the entire detector – corresponding to the large number of modules.

> "We have co-developed several generations of this detector and are familiar with the entire chain of steps, from chip design and installation to data analysis."
>
> Wolfram Erdmann, scientist at the PSI Center for Neutron and Muon Sciences

Two years to produce the modules

Amrutha Samalan carefully places one module after another into the precisely fitting recesses of a white, wired box. "Over the past few years, we have examined and tested various module prototypes and continuously provided feedback to the module designers on potential issues, which are rare but important to address given the large number units," explains the postdoctoral researcher, who has been working in

Lea Caminada's group for nearly two years. In the meantime, the design phase has been completed. Pre-production is under way.

Pre-production means that the researchers are testing a small number of modules to ensure that each production stage is working properly and that the results exactly meet expectations. During this phase, they can also estimate the time required for each production step, so that everything can be scaled up later. Of the approximately 2,000 modules required, nearly half will be assembled at PSI during the actual production phase. The remaining modules will be assembled by the other participants in a Europe-wide consortium, based on the concept developed at PSI. Altogether, they will have two years to produce the 2,000 modules.

"This morning, I used this machine to wire-bond some modules." Samalan points to a unit, roughly the size of a person, in the middle of the lab. "It inscribes the electronic connections we have programmed onto the module – similarly to the way a sewing machine works with thread."

This is followed by a thorough visual inspection, where high-resolution images of each module are carefully scrutinised on a screen for imperfections.

Then, eight modules are inserted side by side into a so-called cold box – the white box that Samalan is now loading. "We perform an important part of quality control in this cold box: We can precisely control the temperature and humidity inside the box and, at the same time, test whether the sensors, readout chips, and pixels are all fully functional," the physicist explains. The researchers also calibrate all detector pixels and their readout channels in this cold box. Each individual module has more than half a million pixels. With a spatial resolution of only ten by fifteen micrometres, they will be able to precisely track particle trajectories in the CMS detector.

Planning the generation after the next

One floor up in the same building, Wolfram Erdmann has just been in discussion with colleagues. He too is a member of Caminada's group. He is leading the international project to design, plan and build the tracker end-cap detector. "After the upgrade, this will be the largest part of the CMS pixel detector in terms of surface area," he says with evident pride.

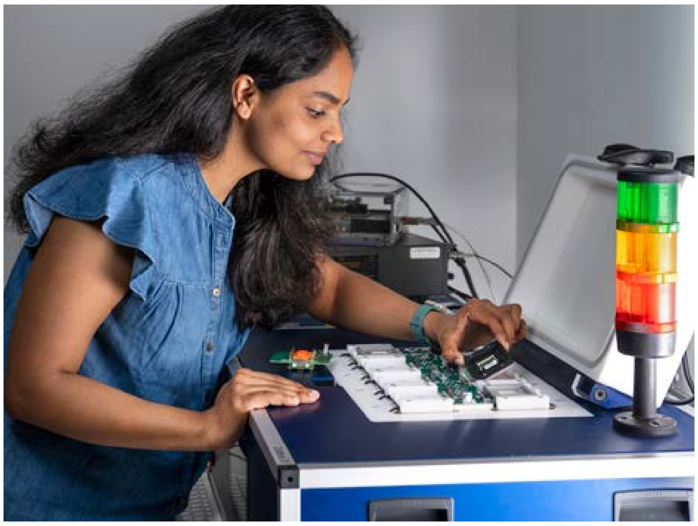
Erdmann maintains contact with the consortium's other research groups at the universities of Zurich, Hamburg, Helsinki in Finland, Santander in Spain, Vilnius in Lithuania, and Zagreb in Croatia. "Here at PSI, we develop many components and many processes that are then replicated at these other locations," says Erdmann. The cold boxes, for example.

PSI has been a member of the CMS experiment since 1998. "This is a significant commitment and requires exceptional expertise," says Caminada. As the world's largest and most powerful accelerator, the LHC is essential for the field of particle physics. The geographical proximity is welcome: "For us, it's very convenient that Switzerland is host country of CERN," says Erdmann.

Caminada's research group is also involved in analysing the data produced by the CMS detector. "We have co-developed several generations of this detector and are familiar with the entire chain of steps, from chip design and installation to data analysis," Erdmann summarises. "Among the institutions involved, that's quite exceptional."

Analysis of data from the tracker end-cap detector, for which production is just ramping up, is expected to start in the early 2030s. In particle physics, planning extends over long periods of time. Accordingly, some researchers are already thinking about the next upgrade after this one. "In fact, that is exactly what I was discussing with my colleagues, just now," Erdmann smiles. In that future upgrade, the researchers' focus will be on enhancing the detector's temporal resolution.

That Erdmann and other researchers are already receiving resources to think this far ahead does not strike the physicist as unusual. From his many years of experience, he knows that "thinking about something is relatively simple. Building it afterwards is where it gets complex." ●



Amrutha Samalan places a series of detector modules into the cold box, where an important part of the quality control process is carried out.

Latest PSI research news

1 Closer than ever to the atomic nucleus

1.97007 femtometres, just shy of two quadrillionths of a metre. That's how tiny the radius of a helium-3 nucleus is. This precise value was determined in an experiment at PSI. To measure it, researchers radically modified a helium-3 atom. Instead of being orbited by the usual two electrons, the nucleus is orbited by a muon, which is around 200 times heavier. Since the heavy muon approaches the nucleus much more closely, their wavefunctions overlap more strongly – making the muon the perfect probe for measuring the charge radius.

A crucial role in this success was played by a special laser system developed in-house. When the frequency of the laser exactly matches the resonance frequency of a specific atomic transition, the muon jumps to a higher energy state for the briefest moment before falling back again within picoseconds, emitting an X-ray photon in the process. By measuring this response, scientists can determine the resonance frequency – and from that deduce the charge radius with extremely high precision.

This experiment was only possible thanks to the muon source at PSI, which is unique in the world, and it sets new standards in nuclear physics.

Further information:
https://bit.ly/45Sw5AY

2 Detecting genetic disorders

Modern medicine is increasingly focusing on identifying disease-related genes early on and deliberately influencing them in a targeted manner. However, for complex diseases such as cancer, Alzheimer's disease or chronic inflammation, it is not enough to examine individual genes – the crucial question is how they interact within the cellular network. The three-dimensional organisation of DNA in the cell nucleus, known as chromatin, plays a key role in this process.

Researchers at PSI have now developed *Image2Reg*, an artificial intelligence that can detect genetic disorders directly in microscopic images of cells. The AI analyses subtle alterations in the chromatin, such as those visible after Hoechst staining, and links them to data on gene activity. This creates a cell type-specific network that reveals how genes interact with each other. In tests, Image2Reg has detected genetic changes with 26 percent accuracy – significantly above the chance level of two percent. In the future, this method could potentially become a fast, cost-effective complement to conventional gene expression analyses.

Further information:
http://bit.ly/463RhoJ

3 Precise radiation against lymphatic cancer

Every year, almost 2,000 people in Switzerland are diagnosed with lymphatic cancer, and around 570 of them die from the disease. Researchers at the PSI Center for Radiopharmaceutical Sciences have now developed an innovative therapy that could offer new hope: radioimmunotherapy using the nuclide terbium-161.

In this therapy, terbium-161 is coupled to an antibody that selectively binds to tumour cells. After being injected, it delivers the radiation directly to the cancer cells while sparing healthy tissue.

Compared to the previously used lutetium-177, terbium-161 offers a crucial advantage: In addition to beta radiation, which spreads over several millimetres in tissue, it also emits Auger electrons with a range of less than one micrometre. This is ideal for the targeted destruction of individual cancer cells or small clusters of cells. Laboratory tests have shown terbium-161 to be two to 43 times more effective than lutetium-177, depending on the cell type.

Researchers are currently preparing clinical trials, aiming to develop a precise new weapon against difficult-to-treat lymphomas.

Further information:
http://bit.ly/45QCk8h

4 AI cookbook for climate-friendly cement

Cement is what holds our modern world together. When mixed with sand, gravel and water, this inconspicuous powder becomes concrete, a building material that can be transported almost anywhere and poured into almost any conceivable shape. It is used not only to construct buildings, bridges and tunnels, overcoming mountains and valleys – even our communications systems run through cables laid underground in protective concrete pipes. Concrete is multifunctional and durable, making it an indispensable part of our infrastructure.

However, cement production has a gigantic carbon footprint. It is responsible for around eight percent of global emissions – more than all the world's air traffic combined. The main contributor to this is the chemical conversion of limestone to clinker, the primary component of cement. This reaction releases CO_2, which is chemically bound in limestone.

PSI researchers have now developed a physics-based, AI-supported model that can be used to discover new cement formulations more quickly – with the same material quality and a significantly smaller carbon footprint. Like a digital cookbook for climate-friendly cement, the model quickly narrows down the most promising formulations, which can then be validated through targeted experiments.

Further information:
https://bit.ly/45LwDbG

Around **1.5** kilograms of cement per person per day – our appetite for cement is enormous.

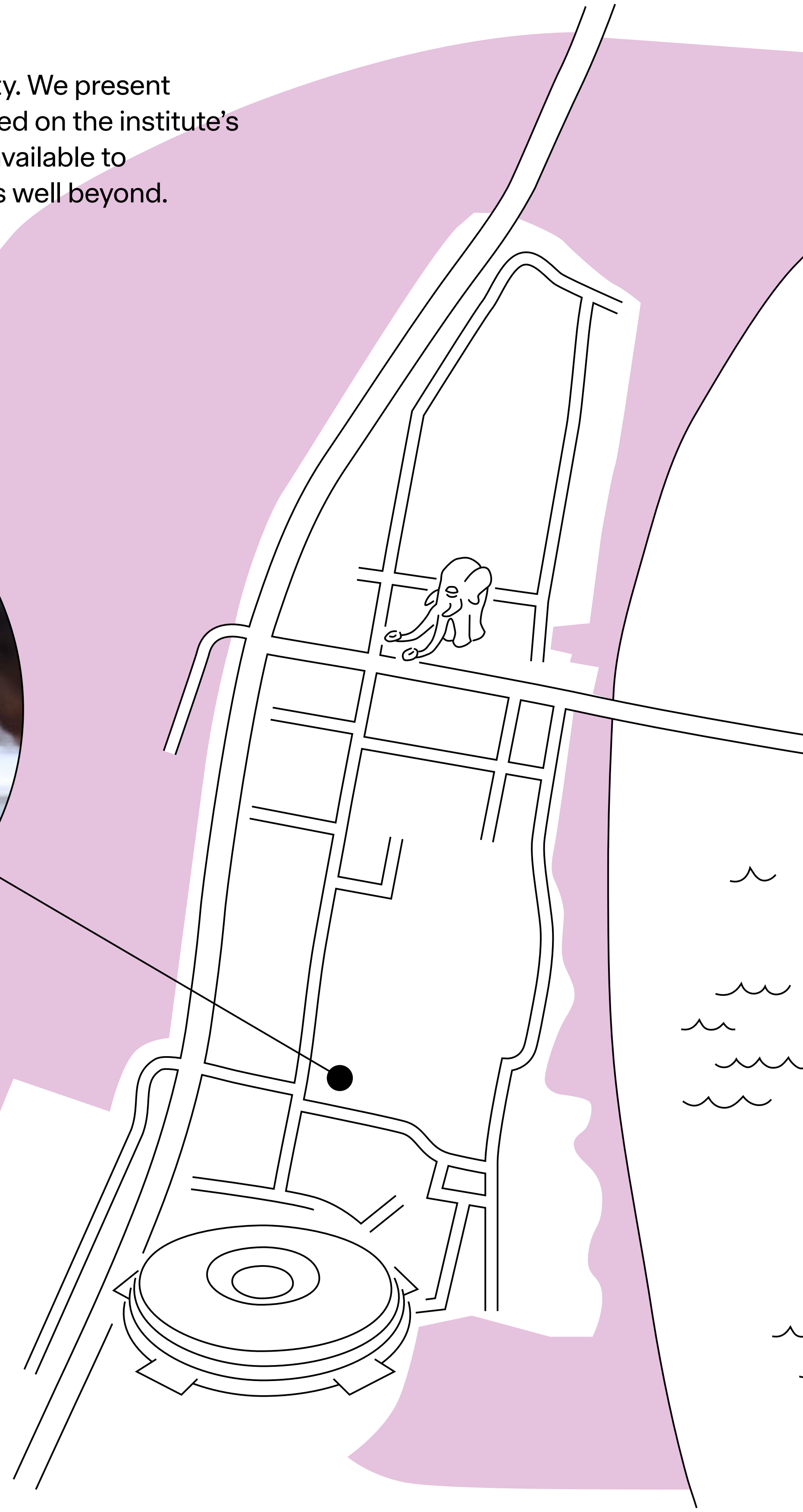
1,000 times faster than conventional modelling: PSI's AI calculates cement properties in hours instead of months.

Around **8** percent of global carbon emissions come from the cement industry – that's more than all the world's air traffic combined.

PSI as a city

If you look closely, PSI resembles a small city. We present a selection of 11 facilities and services located on the institute's 342,000-square-metre campus. They are available to PSI's 2,300 employees – and in some cases well beyond.

Text: Christian Heid



The hospital

Barbara Bachtiary works as a doctor at the Center for Proton Therapy (CPT). Proton therapy is an extremely precise and highly complex form of radiation therapy used in outpatient cancer treatment. Patients are referred from all over Switzerland. In children, it is the gold standard of radiotherapy. In adults, it is used to treat tumours in sensitive areas of the body, for example in the brain, head and neck area, or in areas near nerves.

The fire brigade

In addition to her work as a chemical laboratory technician at PSI, Sasha Alexandra Diaz volunteers with the PSI fire brigade – alongside 90 other employees from all areas of PSI. The campus fire brigade's primary responsibilities are rescuing people and fighting fires. It works closely with the fire brigades in nearby Würenlingen and Geissberg to assist with fighting fires in the surrounding area. The PSI fire brigade also serves as the cantonal radiation protection centre and assists local fire departments throughout the canton of Aargau in emergencies involving radioactive materials.

The mayor

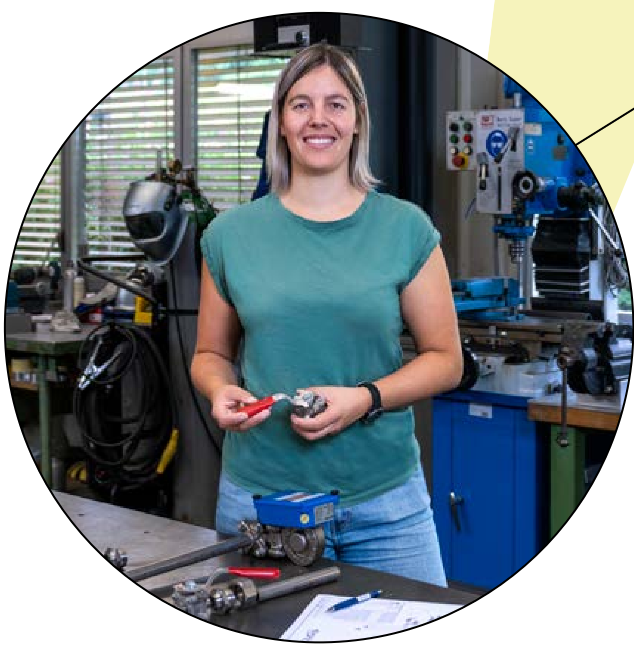
Like the mayor of a city, PSI Director Christian Rüegg has a packed schedule – sometimes stretching into the evenings and weekends, with meetings, interviews, lectures, receptions… Supported by his secretarial and management staff, the heads of the research centers and the research committee, he fulfils his key task of enabling cutting-edge research in the natural and engineering sciences. He campaigns to ensure that Switzerland secures and maintains its prominent position in the international research landscape and that PSI, together with the entire ETH Domain, serves Switzerland in the best possible way.

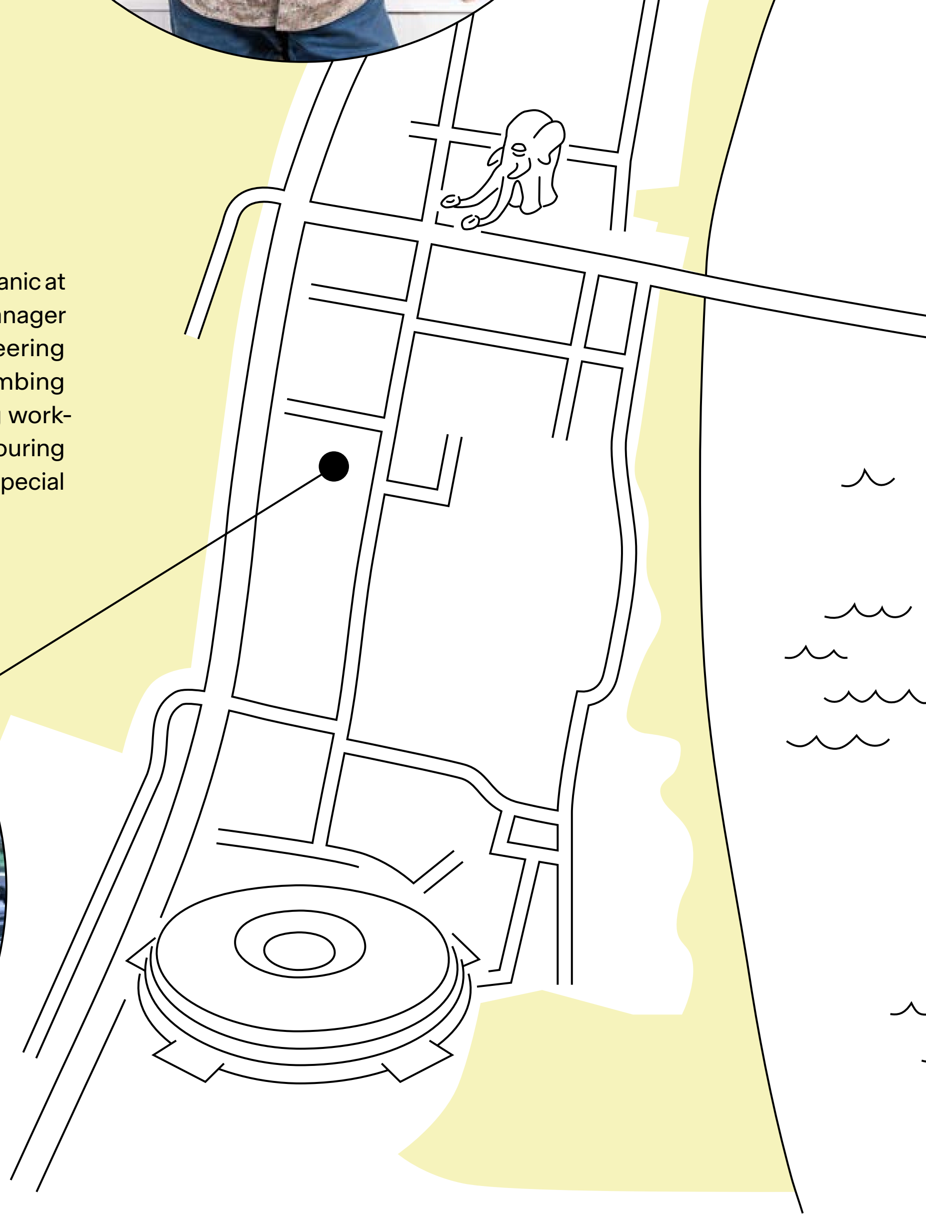
The hotel

PSI has its own guesthouse. Rolf Pederiva works at the reception desk. Sixty-four rooms are available here on three floors, primarily for visiting researchers from all over the world who conduct experiments at PSI's five large research facilities. A team of service staff looks after more than 2,200 guests annually. The guesthouse is located next to a small biotope on the banks of the Aare River, and in addition to the rooms, it offers a shared kitchen, a laundry room, a lounge and an outdoor seating area.

The workshop

Karin Zehnder completed an apprenticeship as a polymechanic at PSI. Today, she works as a design engineer and project manager for the process cooling section in the hydraulic engineering workshop. In addition to an electrical workshop, a plumbing workshop, a steel construction workshop and a training workshop on campus, PSI also has a workshop in the neighbouring Park Innovaare. Various technologies are used here – from special joining techniques to traditional machining.





The laundry

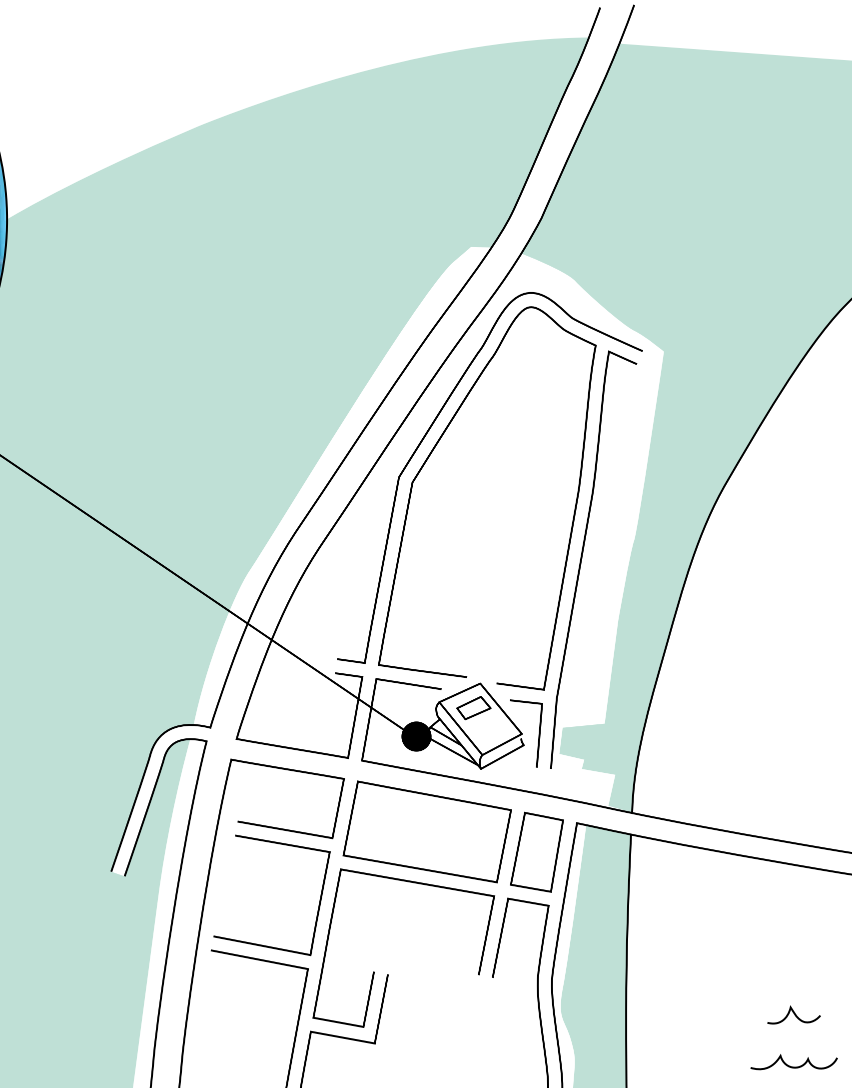
Senta Schneider and her three colleagues handle around 73 tonnes of laundry annually at PSI's in-house laundry facility. The team also runs the clothing and shoe storeroom, where all PSI employees can obtain the personal protective equipment they need for their work. In the laundry, clothing is professionally fitted, maintained and repaired when necessary, ensuring that all employees have access to clean, functional and safe workwear at all times.

The day care centre

Lino Bärtschi hands out wooden blocks, reads aloud, changes nappies, provides food and offers comfort. As an apprentice at the Nanolino day care centre, he is part of a team, divided into six groups, that looks after some 120 children. The PSI day care centre is open to infants and toddlers from three months of age. This service is used primarily by parents who work at PSI, but also by families who live in the area. The new, modern building opened in the summer of 2025, and in its playful garden landscape the little ones can play to their heart's content thanks to a track for ride-on cars, a marble run, a sandpit and a water pump. Walks in the adjacent Würenlingen forest are also part of the children's routine almost every day.

The library

Naturally, books play an important role for Stephanie Hofmann and the Lib4RI library team. However, the reference collection now makes up only a small part of what is on offer. Access to digital media is more important. There is also a small reading room for undisturbed work. The library helps PSI researchers to search through scientific literature and supports them in publishing their research results. A wide range of training courses are also available, covering topics such as the professional handling of research data, copyright and open access.



The restaurant

Preparing hot and cold dishes and beautifully presenting them is part of Remy Bonetta's daily work. As an apprentice, he is one of 40 employees at the PSI staff restaurant Oase and the adjoining cafeteria. At lunchtime, between 11:30 and 13:30, PSI employees and visitors can enjoy daily changing menus and a buffet. PSI's catering facilities also include another cafeteria in the eastern part of the campus as well as the restaurant Culinaare, with a coffee bar, to the west of the Aare River in Park Innovaare.

The museum

PSI also opens its doors to the public with its own museum, the PSI Visitor Center, where admission is free. Here Grégoire Saerens and his colleagues welcome visitors from Monday to Friday and on Sundays, from 13:00 to 17:00. The 13 interactive exhibits on display give visitors hands-on insight into the different kinds of research taking place at PSI. Visitors who register in advance can also book a free guided tour of the PSI grounds and get a glimpse inside one or more of the research facilities. A special visitor experience is available to school classes: having been registered by their teachers, around 200 classes each year can spend a day at the PSI iLab, where they can conduct their own experiments under expert guidance.

The gym

Side stretches, shoulder bridges, abdominal work. Reto Fortunati is an engineer at the PSI Center for Accelerator Science and Engineering, but during his lunch break, he regularly teaches Pilates in the sports hall on the PSI campus. His classes are open to the 750 members of the PSI Sports Club, which also offers badminton, football, climbing, dance, yoga and much more. The running group takes advantage of the extensive forests around PSI. Others meet to swim in the Aare River – the hardiest of them even brave it in winter.

Where analysis meets flavours

Some see brewing as an art, others as a science – Luc Van Loon combines both these virtues at his brewery. With the nose of a sommelier and the precision of a chemist, the former PSI researcher creates world-class beers.

Text: Benjamin A. Senn

The entrance to the brewery is inconspicuous, tucked away in a quiet residential street in Neuenhof – a tranquil Aargau village where stately half-timbered houses and babbling fountains make you forget the hum of the nearby motorway. Here, hidden in an old wine cellar, is the Chen Van Loon brewery. And this is also where the Sauvignon Ale is produced – the beer that, in 2024, was voted the third best beer in the world by the jury at the Finest Beer Selection, an internationally renowned competition.

Small but outstanding, you could say. "We're a microbrewery," explains Luc Van Loon, master brewer and former PSI chemist. Ten different beers are produced here – with a maximum capacity of 32,000 litres per year. "That's how much Feldschlösschen produces in one hour," he adds with a wink, referring to Switzerland's largest and best-known brewery. "We're definitely in a different league – our focus is on artisanal diversity and creative brewing styles. And that's exactly what convinced the jury."

But how does a chemist end up brewing beer? Admittedly, the process itself can be expressed precisely in formulas – it's pure chemistry. But Luc Van Loon came to beer not because of science, but through wine.

From chemist to winemaker to brewer

In 2005, Luc Van Loon leased a 0.3-acre vineyard and started producing wine in his spare time in the cellar of the winery Weingut zum Sternen in Würenlingen. At that time, the native Belgian had been working at PSI, just around the corner from his vineyard, for almost 20 years. Originally, he had applied for a position at the Swiss National Cooperative for the Disposal of Radioactive Waste (Nagra). But there were no vacancies at the time, so his documents were promptly forwarded to PSI. He sums up what followed: a call from PSI, a one-day on-site interview, and a friendly "You can start right away."

And so, on 2 November 1988, the Van Loons and their two sons emigrated from Merksplas in Belgium to Kleindöttingen in Switzerland. Luc Van Loon had previously earned his doctorate in radioecology from the Faculty of Agriculture at the University of Leuven. His dissertation examined the behaviour of the long-lived radionuclide technetium-99 – a legacy of the nuclear weapons tests of the 1960s – in agricultural products. Thus, his studies had already given him a keen understanding of soils, agriculture and how people shape them.

While Van Loon tended the vines in his spare time, harvesting grapes in autumn, pressing them and fermenting their juice, the substances he studied as a geochemist and head of the Diffusion Processes Research Group at PSI were very different. "We wanted to understand how radioactive substances behave in different materials – for example, how radionuclides migrate through Opalinus Clay and what interactions take place there," Van Loon explains.

Opalinus Clay is a fine-grained claystone that formed around 173 million years ago from mud deposits on the seabed. Today, it lies several hundred metres underground and is of particular interest for storing radioactive waste in deep geological repositories, where it can serve as a natural barrier. "Our studies have contributed to a better understanding of the barrier properties of this rock," says Van Loon.

The experiments were conducted in the Hot Lab at PSI, a unique facility for the analytical investigation of highly radioactive substances. Access is strictly controlled through security gates, and the lab is surrounded by thick concrete walls. Lab coats are mandatory, and fresh air is scarce. "The physical labour in the vineyard was a welcome relief," says Van Loon with a smile.

This work sometimes left him sweaty – and thirsty. "You have to drink a lot of beer to make a good wine," joked Australian Christopher Chen about the hard work in the vineyard. At the time, Chen was working as an oenologist at Weingut zum Sternen and discovered a fellow beer enthusiast in the hobby winemaker Van Loon – who, as a Belgian, also hails from a true beer-loving nation. And so, in 2013, the two friends began brewing their first beer, purely on an experimental basis, using an old cauldron in the wine cellar.

Beer for beginners – a basic recipe:

- Mix malt with water and heat to 65 °C – this produces sugar.
- Filter the resulting “wort” and heat to approximately 98 °C (sterilise).
- Add hops – for flavour and bitterness.
- Place in a fermentation tank with yeast for about ten days – this produces alcohol and carbon dioxide.
- Chill the young beer to 10 °C and bottle it.
- For additional natural carbonation: add some yeast and sugar and wait for bottle-fermentation to finish.

“We are a true family business – and that’s great.”

Luc Van Loon, Master Brewer

Because they had no bottles prepared for bottling, they had to make do with some old champagne bottles from the cellar – and thus was born, quite by chance, the distinctive shape of the bottles that remains their beer brand’s signature today. Soon, they invested in a 200-litre system – but production increasingly clashed with the wine business. So, in 2015, they moved to Neuenhof – once again setting up in an old wine cellar.

The science of brewing

Although beer is made from four simple ingredients – water, malt, yeast and hops – the variety of flavours they can produce is almost limitless. “There are more than 50 types of malt and around 200 types of hops – not to mention the countless strains of yeast,” says Van Loon. External parameters such as temperature, fermentation time and storage also shape the beer’s character. “For me, that makes beer much more exciting than wine.”

Luc Van Loon fills a glass with golden, amber-hued liquid from the tap of one of the large, silvery fermentation vats and carries it to his standing lab bench. Armed with a pipette and an array of measuring instruments, he begins his analysis. All that’s missing now are the lab coat and the gloves – and you could imagine yourself back in a PSI laboratory rather than a brewery.

The drop from the pipette lands in the refractometer. This instrument looks a bit like a telescope, but instead of looking into the distance, it is used to peer inside the liquid. Depending on the density of the beer, the incoming light is refracted at a different angle – this allows you to determine the sugar content. That in turn reveals how far fermentation has progressed in terms of how much sugar has already been converted into alcohol. An infrared device for measuring the effective alcohol content and a pH electrode are also available. “All that’s missing is a device for determining bitterness and colour,” says Van Loon. “Then my lab would be complete.”

When Luc Van Loon talks about his analytical methods, you realise you’re not just encountering a passionate brewer at work here but also an experienced scientist – one who is also well-versed in quality control. At PSI, Van Loon was responsible for quality management in the Laboratory for Waste Management at the PSI Center for Nuclear Engineering and Sciences. “It’s no different in a brewery,” says the brewer. “Here, too, we maintain strict records of our procedures and check the quality of our products – after all, the beer should always taste the same – with consistent colour, alcohol content and character.”

From a lark to a family business

Luc Van Loon has been brewing beer for more than a decade – and since his retirement in 2024, he no longer just brews on weekends. His former brewing partner, Christopher Chen, has since left the business and returned to his native Australia. Van Loon’s son, Jan, has joined the company – full-time. “I’m very proud that he’s taken the step into self-employment,” says Van Loon. The rest of the family is also on board: Jan’s partner takes care of graphics and marketing, and Luc Van Loon’s wife Anita handles the accounts. “We’re a true family business – and that’s great.”

At the moment, the Van Loons are working with a bachelor’s student from the Zurich University of Applied Sciences (ZHAW), exploring the potential of wine yeasts to release specific aromatic compounds in beer. “Our Sauvignon Ale, last year’s winning beer, contains a dash of grape juice from our own vineyard to enhance its fruity flavour,” Van Loon explains. “Our Vigneron – Cuvée du Patron, another award-winning beer, also tastes grapey but contains no fruit at all. The flavour comes entirely from the yeast. Its microbiological diversity holds enormous potential for new beer styles.”

Even in retirement, Luc Van Loon’s passion for experimentation and scientific work is undiminished. And his beer creations remain successful: in this year’s Finest Beer Selection, two Chen Van Loon beers achieved an impressive 95 out of 100 points – further proof that art and science can harmonise perfectly in the glass. ●

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Editorial team
Monika Gimmel
Martina Gröschl
Christian Heid
Dr. Laura Hennemann (Lead)
Benjamin A. Senn
Dr. Mirjam van Daalen

Translation
Patrick Regan

Editor
Daniel Bullinger

Design concept
Scholtysik & Partner AG and
Studio HübnerBraun

Design, Art Direction and Layout
Studio HübnerBraun

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Paul Scherrer Institute PSI/
Markus Fischer, except:
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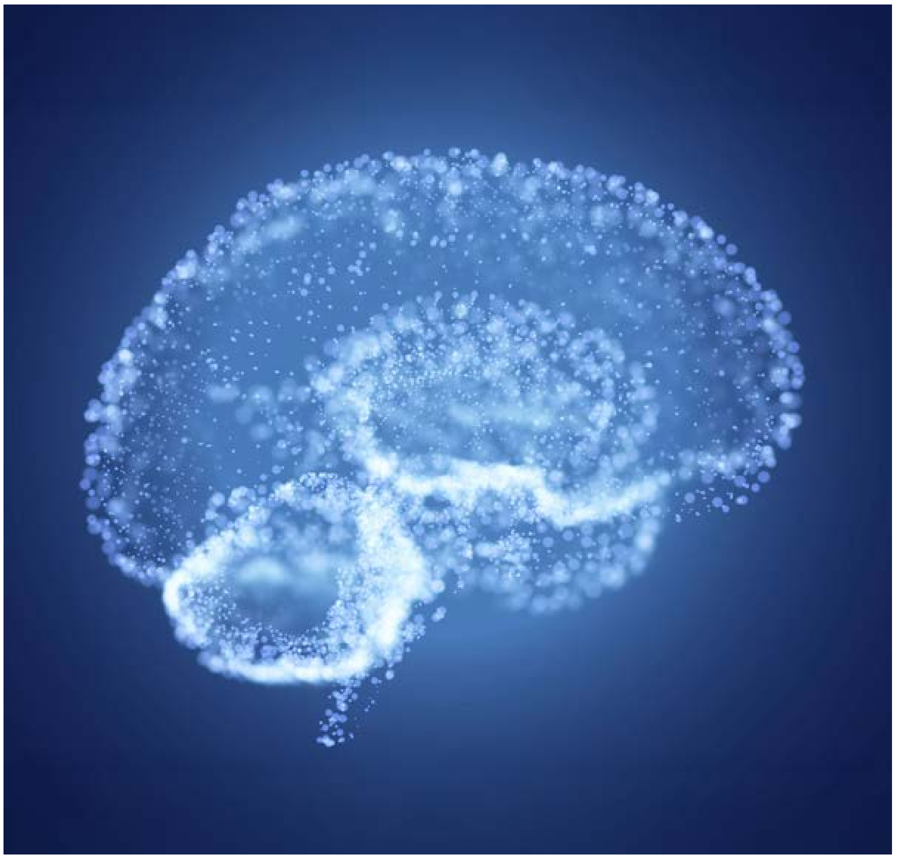

In the next issue: Science for healthy ageing

Thanks to advances in science and medicine, our life expectancy is increasing – and with it our hope of staying healthy for a long time. So we pay more attention to our diet, motivate ourselves to exercise, and try to reduce stress. How can research support us in our quest for a high quality of life in old age? What new approaches are emerging for diagnosing and treating cancer, one of the most common age-related diseases? What does the future hold for personalised medicine? What do we know about the precise structure and function of the brain – and where is more fundamental research needed today to ensure the best possible diagnoses and treatments for neurodegenerative diseases tomorrow?

The next issue of 5232 will take you on a journey through the latest research and offer insights into the future of healthy ageing.

5232 – the address for research

The Paul Scherrer Institute PSI is the largest research institute for natural and engineering sciences in Switzerland. 5232 is the institute's own postal code – and also the name of the PSI magazine. In it we share stories about the science done at PSI, report on the people who work here and show how research leads to progress.

Paul Scherrer Institute PSI
Forschungsstrasse 111
5232 Villigen PSI, Switzerland
www.psi.ch