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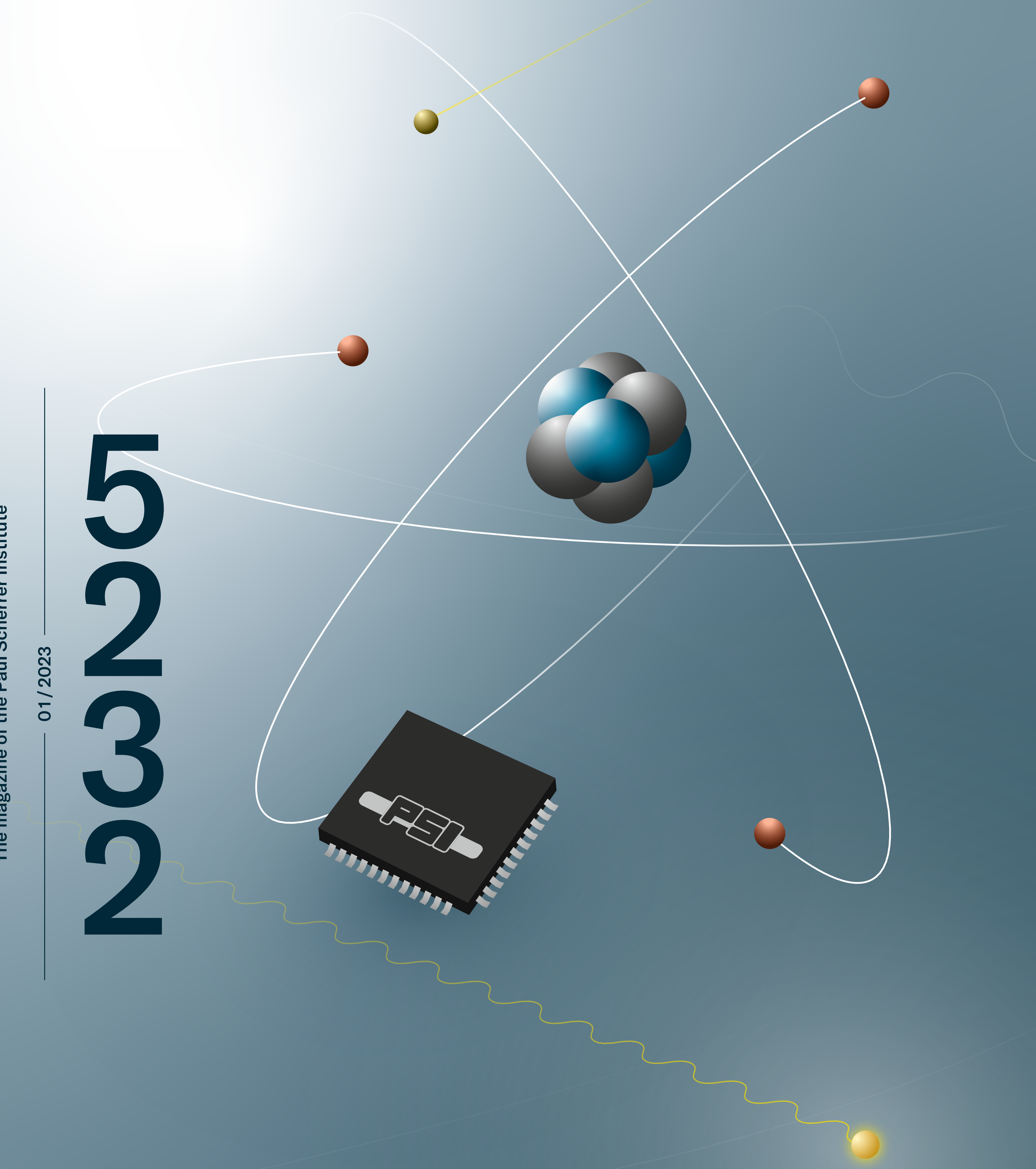
The magazine of the Paul Scherrer Institute

01/2023



KEY TOPIC

MEASURING THE MICROCOSM

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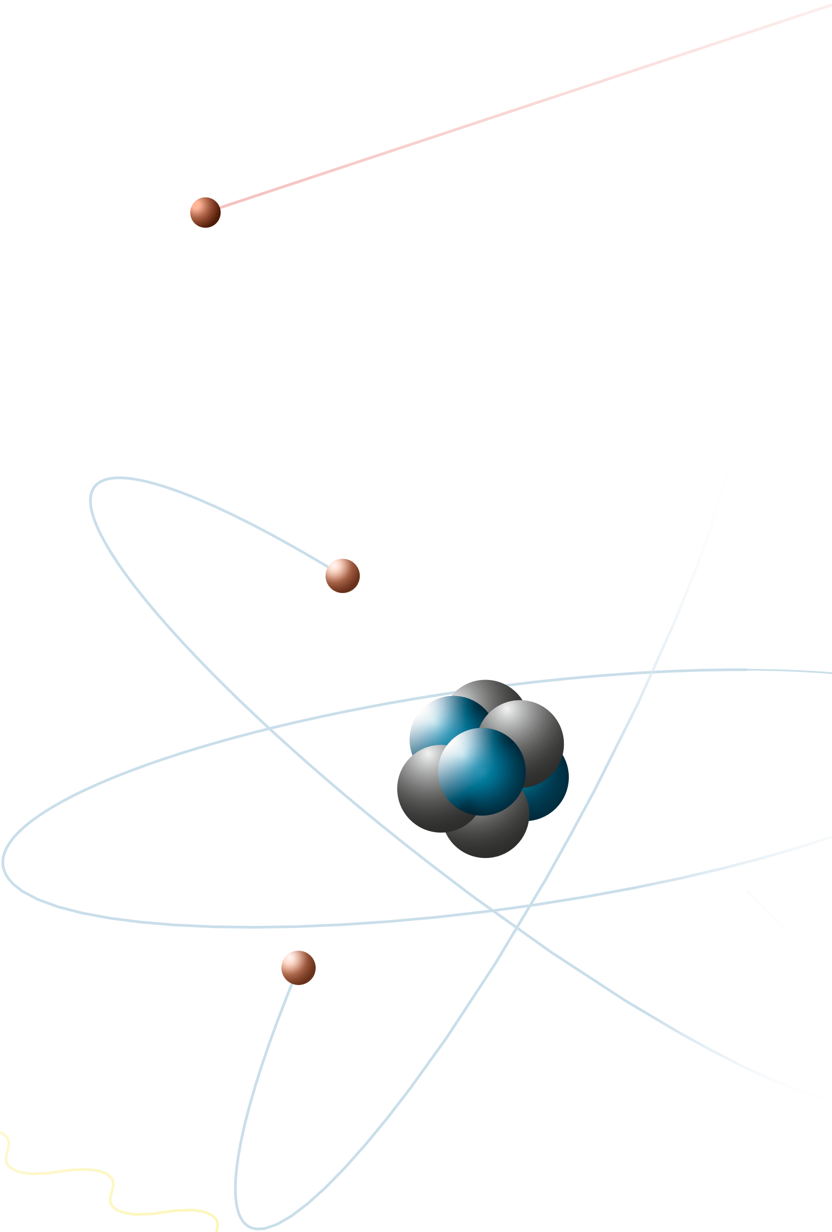

BACKGROUND

More light in the darkness

Researchers are trying to find gaps in the theory of the Standard Model of particle physics. PSI's unique infrastructure plays a key part in their mind-boggling experiments.

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INFOGRAPHIC

The Standard Model of particle physics

Elementary particles are the smallest building blocks of nature. The Standard Model describes their properties and the ways they interact with each other. But some of its mysteries have yet to be solved.

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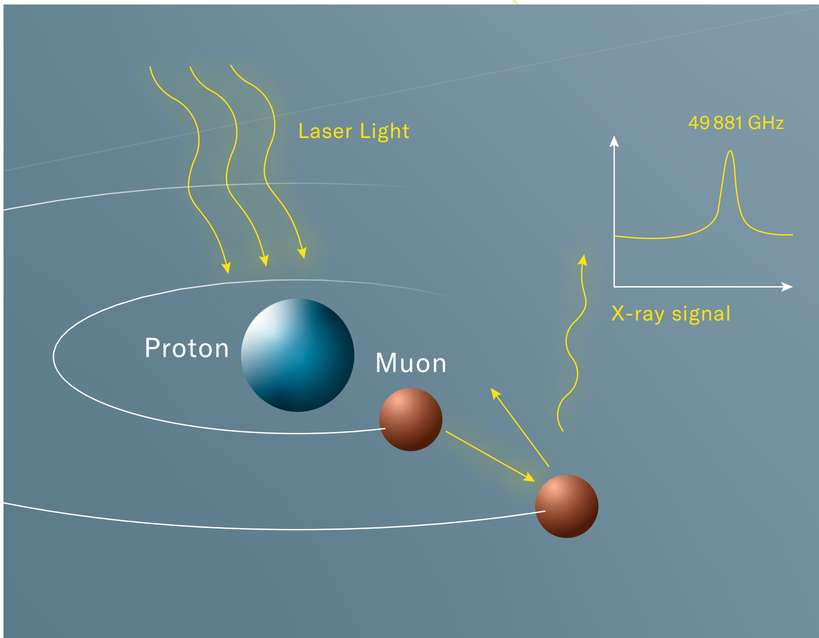
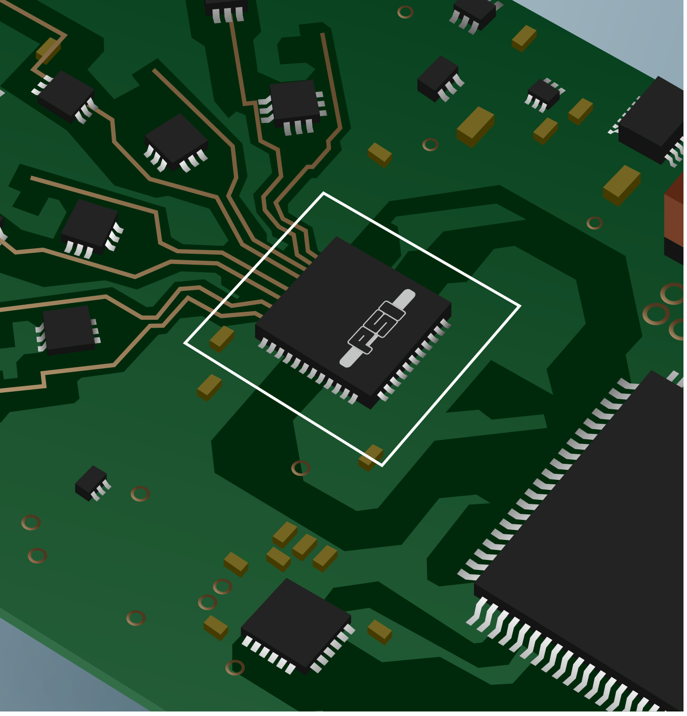
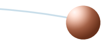




REPORT

What can’t be bought, we develop ourselves



For many experiments at the limits of scientific knowledge, there are not yet any technical solutions. That’s why researchers at PSI simply develop these themselves – thus encouraging many other applications in science and industry.

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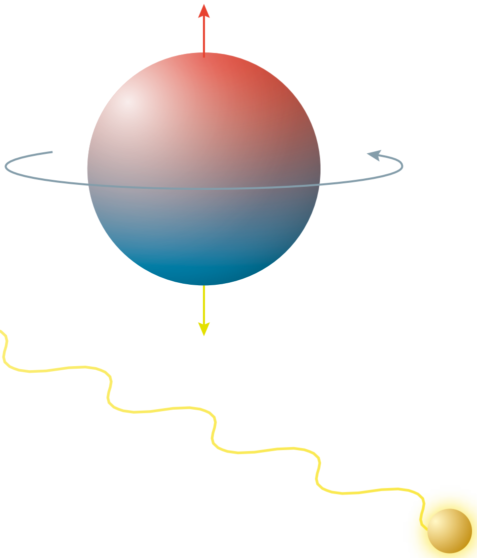

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An apprenticeship in Oase, PSI’s staff restaurant, provided the basis for Michaela Frank’s career as one of the youngest top chefs in Switzerland.

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PSI Director Christian Rüegg

Creating fundamental knowledge

I'm standing here at one of PSI's essential machines, the large cyclotron that is an important part of our proton accelerator facility. In it, protons – small, positively charged particles that are important building blocks of atomic nuclei – are accelerated to around 80 percent of the speed of light, generating the most powerful proton beam in the world. That in turn is used to produce other particles, such as neutrons, pions or muons, which enable us to conduct extraordinary investigations and experiments.

For many, this world of the smallest particles – of which our world is composed – may seem bewildering. But it opens up unique insights and findings – from the smallest scales of the atomic and subatomic to the largest we're aware of: the universe. This may sound theoretical at first, but it is crucial for further scientific and technological developments. We can look deep inside materials with the aid of neutrons or muons. By means of so-called ultracold neutrons or, for example, muonic hydrogen, we are searching for new fundamental knowledge about the building blocks of our world. Researchers at PSI have gained fundamental insights into particle physics and have measured both the aforementioned proton and the nucleus of the element helium more precisely than ever before. Just to make some experiments feasible in the first place, we at PSI also develop technologies such as high-performance electronics and high-precision detectors, for which there is global demand.

We haven't yet uncovered nature's ultimate secrets, and the models we want to use to decipher them remain incomplete. With every new insight we gain, we come a bit closer to the solution of the mystery and often discover new surprises. The researchers' curiosity about this unknown territory serves as a crucial driver in overcoming all obstacles on the way to further fundamental insights.

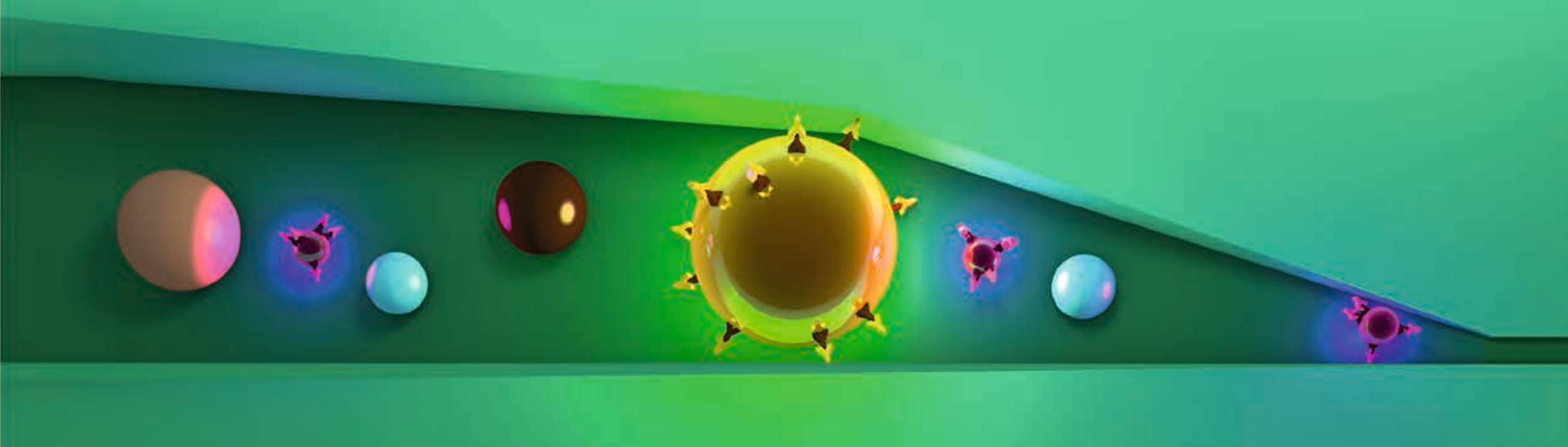
Besides this aspect, which borders on the philosophical, the results of basic research also have an impact on practical matters. Thus findings from relativity theory have a decisive influence on the functionality of today's navigation systems such as GPS. What was conceived and recognised at the beginning of the last century has now found its way into our daily lives. And so researchers at PSI are working today to create further fundamental knowledge in order to shape the future positively for as many people as possible.

Wipe and away

Who hasn't experienced this? A cup of coffee or glass of fruit juice tips over, and the puddle keeps spreading. It's good if this happens on a smooth surface and not on a tablecloth. Then the mishap can be easily remedied, for example by mopping with a sponge. It absorbs liquids effectively – thanks to the capillary effect. This describes the phenomenon whereby liquids rise into fine cavities. But that only happens if the attractive force between the wall of the cavity and the particles of liquid is larger than that between the liquid particles themselves. The finer the cavities, the stronger the capillary force and the higher water, for example, can rise. The capillary effect occurs, to name a few examples, in kitchen towels, blotting paper and plants. It is one of the mechanisms plants use to transport water upwards against gravity. So we owe it to the capillary effect that flowers in a vase filled with water do not dry out, that grain can grow in the fields, and that we can enjoy majestic forests. It's partly due to the capillary effect that trees can manage to transport vital water up to heights of well over 100 metres.

Bind and stick

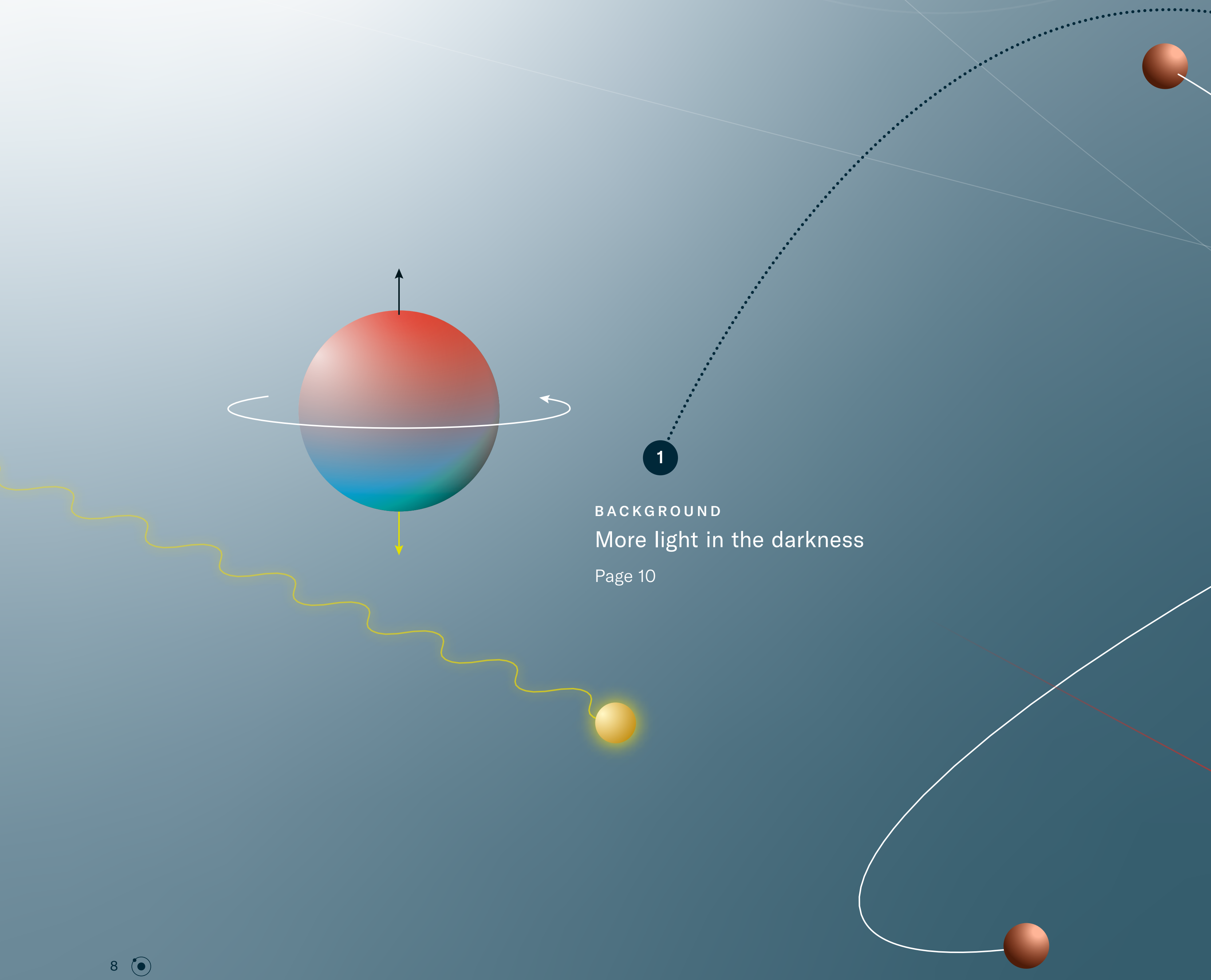
Researchers at PSI were using the capillary effect to develop a rapid test for the Sars-CoV-2 virus and other pathogens. The central component consists of a small, rectangular slab of normal Plexiglas. On it are small channels. Crucial to the test is a passage where the height of the channel drops from 3.4 to 0.8 micrometres, like a funnel. For the test, a drop of blood is taken from the subject. The blood is mixed with a liquid in which special artificial nanoparticles are suspended. Their surface has the same structure as proteins of the Sars-CoV-2 virus. Human antibodies normally dock on these antigens to fight the pathogen. Also blended in are fluorescent particles that attach to the Sars-CoV-2 antibodies in humans. If the test sample contains antibodies against Sars-CoV-2, the fluorescent particles attach to them. Together they then attach themselves to the virus-like structures on the nanoparticles. Then the capillary effect draws this test liquid through the channel, and the nanoparticles with fluorescent antibodies get stuck where the channel becomes too narrow. Nanoparticles of different sizes can be equipped with antigens of specific viruses. Depending on where fluorescent particles are detected, it is possible to determine which virus has infected the test subject.



KEY TOPIC

Measuring the microcosm

At PSI, researchers want to fill the missing gaps in the Standard Model of particle physics. As they continue to make new discoveries, they may ultimately shake the foundation of the current model. To acquire this fundamental knowledge, they use the large research facilities at PSI – and often, completely new technology. They simply build it themselves if necessary, as in the case of special sensor chips.



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BACKGROUND

More light in the darkness

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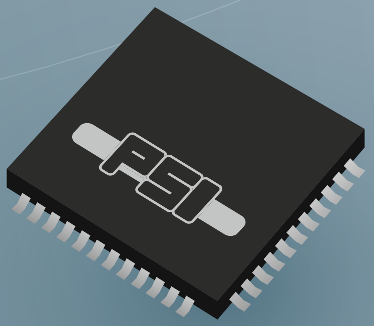

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INFOGRAPHIC

The Standard Model of particle physics

Page 16

3

REPORT

What can’t be bought, we develop ourselves

Page 18

More light in the darkness

The Standard Model of particle physics describes our visible universe with incredible precision. Yet researchers are not entirely satisfied with it and are trying to find gaps in the theory. PSI's unique infrastructures play a key part in their mind-boggling experiments.

Text: Bernd Müller

Picture a dark room. Standing in the middle, a pedestal supporting a work of art fashioned from pure gold and magnificent gemstones, resembling the death mask of Pharaoh Tutankhamun. Nothing should divert your gaze from this perfect beauty. There is just such a work of art in physics: the Standard Model of particle physics. It describes all visible particles of the universe, as well as three of the four forces of nature within it. All experiments that have been performed on – or with the aid of – elementary particles confirm this theoretical concept, again and again. So there's no reason to peer into the dark corners behind the Standard Model, right?

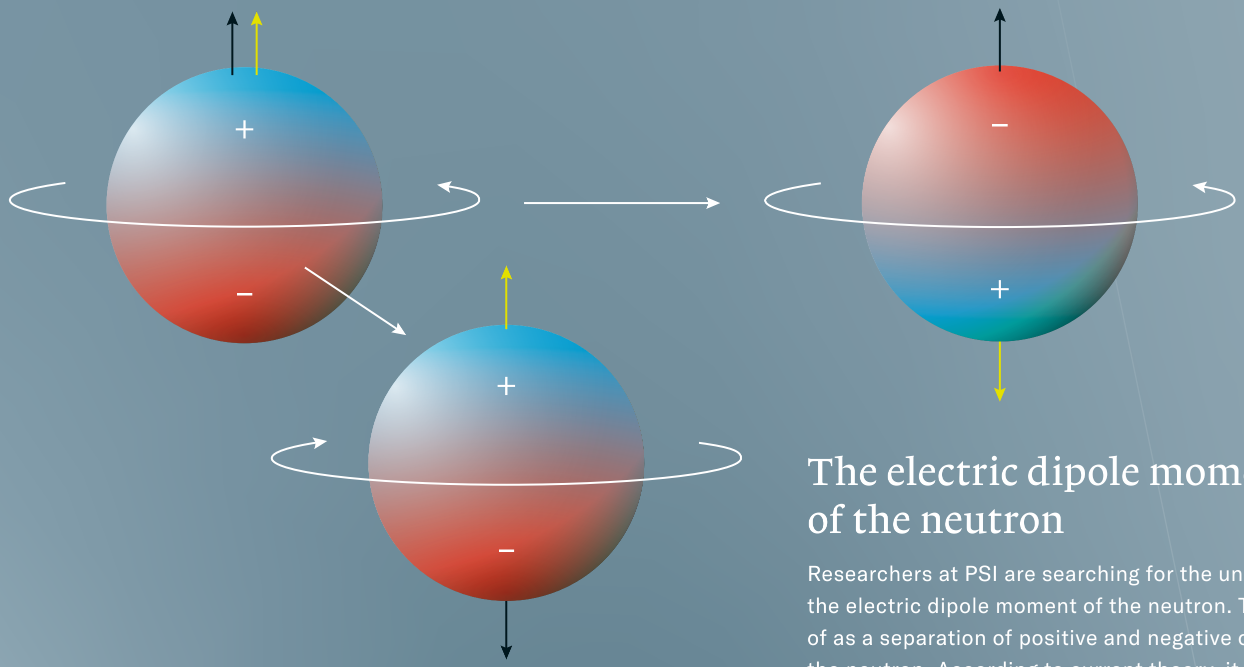
At PSI, Klaus Kirch works on the foundations of physics, for example the most precise measurement possible of properties of the smallest building blocks of matter.

Klaus Kirch disagrees. "We are very happy with the Standard Model," says the head of the Laboratory for Particle Physics at PSI and professor at ETH Zurich. "But it's not the last word." That's typical for a physicist: no theory is so perfect that it can't be questioned. And the Standard Model is far from perfect. It leaves several questions open, such as how gravitation can be compatible with the other three forces of nature. Or why there can never be "nothing": because after the Big Bang, more matter was left over than antimatter, whereas according to all theories they were created in exactly the same proportions and should have annihilated each other. Anyone deeply involved in astrophysics is perplexed by the fact that stars in galaxies move as if a large invisible mass were tugging on them. They use the term "dark matter" to describe this poorly understood phenomenon. Although it has never been observed, researchers are sure it exists.

These are all questions for which the Standard Model gives no answer. "That's why we're trying to bring light into the darkness where the inconsistencies are especially great," Kirch says. Numerous experiments serve as "flashlights" meant to illuminate even the dark corners. That's difficult, though, because the Standard Model outshines everything. So one needs particularly sharp eyes to see something back there.

There are basically two complementary ways to achieve this. At PSI, physicists use high-precision equipment to observe particles with very low energies in order to detect extremely rare transformation events. These experiments are smaller than the alternatives and usually cost only a few million Swiss francs; the teams are a manageable size of 50 to 100 researchers, where everybody knows everyone else. PSI has an outstanding global reputation in this discipline and is in fact the only place some experiments can be carried out with such precision.

Researchers at CERN are taking the second path: they fire particles with high energies at each other and observe whether new heavy particles arise from the concentrated energy. Such experiments are CERN's specialty and require gigantic



The electric dipole moment of the neutron

Researchers at PSI are searching for the undiscovered: the electric dipole moment of the neutron. This can be thought of as a separation of positive and negative charges within the neutron. According to current theory, it shouldn't exist, since the neutron is externally electrically neutral – and to date, it hasn't been detected. But if even a tiny dipole moment could be measured, it would be a clue to new physics.

machines such as the 27-kilometre-long ring cyclotron Large Hadron Collider (LHC), where many thousands of researchers work.

Shielding chamber in a class of its own

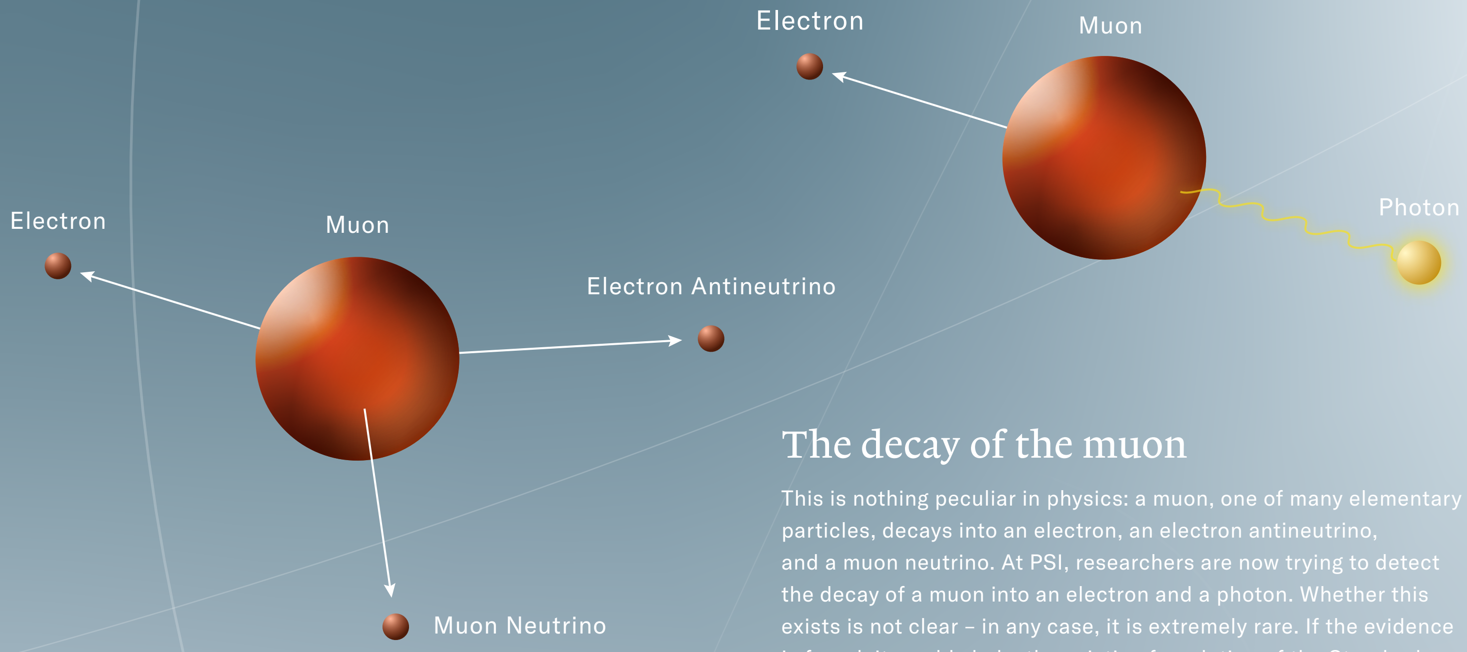
The provisional crowning glory of the experiments conducted at PSI is n2EDM. PSI researchers love abbreviations like this; they immediately tell insiders what is being investigated. In this case it is the electric dipole moment of the neutron. The Standard Model essentially says that the neutron has no electric dipole moment measurable by current means. There are theories, however, that allow it. These assume that there might be a tiny charge separation inside the uncharged neutron. If this dipole moment were measured experimentally, these theories could at least partially explain the dominance of matter over antimatter.

To make such a measurement possible, however, the researchers have to block out any interfering magnetic field, in particular the Earth's magnetic field, because the electric dipole moment of the neutron – if it exists at all – is extremely weak. To this end, Klaus Kirch's team has built a shielding chamber weighing more than 25 tonnes, with walls made of several layers of a nickel-iron alloy. Within this five-metre-tall colossus stands a second chamber that further reduces the magnetic field. The field inside is a hundred thousand times weaker than outside. That makes this room the best magnetic shielding chamber on this scale worldwide.

The experiment takes place inside the chamber, where ultracold – that is, slow – neutrons are exposed to a magnetic field that causes the neutron's magnetic dipole moment to rotate. If an additional electric field is applied, the rotation should change – but only if the aforementioned electric dipole moment exists.

The predecessor experiment nEDM yielded a "result compatible with zero", which is the researchers' ironic way of saying they haven't found anything. But that doesn't mean the effort was a failure, according to Kirch. Each experiment should push the boundaries of knowledge and illuminate the space around the Standard Model a bit more. The n2EDM

> "We're trying to bring light into the darkness where the inconsistencies are especially great."
>
> Klaus Kirch, head of the Laboratory for Particle Physics



The decay of the muon

This is nothing peculiar in physics: a muon, one of many elementary particles, decays into an electron, an electron antineutrino, and a muon neutrino. At PSI, researchers are now trying to detect the decay of a muon into an electron and a photon. Whether this exists is not clear – in any case, it is extremely rare. If the evidence is found, it would shake the existing foundation of the Standard Model of particle physics (see also infographic, page 16).

experiment is ten times more sensitive and will shed extra light into one of the dark corners – no matter how it turns out.

Clue to new physics

Physicist Philipp Schmidt-Wellenburg is taking an alternative route with an experiment that has not yet been attempted in any other laboratory worldwide. He is also looking for the electric dipole moment, but with muons. He uses strong magnets and electric fields to force muons to follow a circular path. If the alignment of the muon spins changes – a quantum mechanical property of the particle that can be imagined as a tiny compass needle – it would mean that the muon must have an electric dipole moment. That would also be a clue in the discovery of new physics.

Klaus Kirch is 54 years old and therefore still has at least a decade to find results that are not compatible with zero. But what if that does not work, if all these experiments absolutely refuse to reveal any new physics beyond the Standard Model, if the corners actually appear empty, no matter how brightly you illuminate them? This would in the first place be positive, by giving further proof of how well the Standard Model describes nature. However, Kirch does not believe this will happen. “We’re going to find something. There’s too much evidence that the Standard Model is incomplete.”

Angela Papa sees it that way too. As a particle physicist, she conducts research with muons at PSI and is also a professor in Pisa. Two-hundred million of these heavy relatives of electrons are delivered to beamlines at PSI every second. That makes them the most intense continuous muon sources in the world. Since 2019, after improvements in muon production at several beamlines, there have been around 50 percent more muons. The MEG2 experiment, a more powerful successor to the MEG experiment completed in 2013, has been running at one of these beamlines since 2021. MEG is the abbreviation for muon-electron gamma and stands for an event in which a muon does not behave as usual, but decays into an electron and a photon (gamma) – that is, a high-energy light particle. This occurs extremely rarely, if at all: no one has been able to observe this decay before. If it’s found to exist, it would be evidence of physics beyond the Standard Model. And if not? “That would also be interesting,

> “If there were a specific, extremely rare muon decay, it would be evidence of physics beyond the Standard Model.”
>
> Angela Papa, particle physicist

because it would allow us to rule out certain theories and limit ourselves to a few models in future experiments," Papa says.

If the MEG decay is not detected, it would strengthen the Standard Model of particle physics, which considers the exotic decay so improbable that it could never be observed. Thus only one out of 10^{54} muons (a number with 54 zeroes) should follow this decay path. At present, such an event can only be detected if at least one out of 10^{14} muons decays in this way. Even the best experiments will never be able to bridge this enormous gap, but the researchers hope the event will show up sooner. Some variants of supersymmetry, a hypothesis in which every particle in the Standard Model has a heavy superpartner, allow the rare muon decay within the measurement limits that experiments at PSI will reach in the coming years.

Particle physicist Angela Papa's research activities include the MEG2 experiment at PSI. She's looking for an extremely rare kind of muon decay (see also graphic, left).

A major coup

It would be a major coup if PSI researchers were to find any indication of supersymmetric theories. While the Standard Model could be extended for supersymmetry, there are also experiments that could shake the theory to its core. You know the saying: "What goes up must come down." Nothing ever falls upwards. If you drop a coffee mug, it will shatter on the floor, never on the ceiling. But is that really always the case? Couldn't there be a form of matter that is repelled in a gravitational field and falls upwards? To investigate this, PSI researchers are planning an experiment with muonium, an exotic atom made from a positively charged anti-muon and an electron. It is similar to hydrogen, but the proton is replaced by antimatter in the form of a point-like lepton, another type of elementary particle. Since muonium, in contrast to normal hydrogen, consists of two point-like leptons, it lends itself to precise calculations with quantum electrodynamics (QED), which describes electromagnetism in terms of quantum theory. Further experiments could measure the energy levels of this atom and check whether QED theory and experimental observation yield the same results, which in turn would have predictive advantages for future experiments.

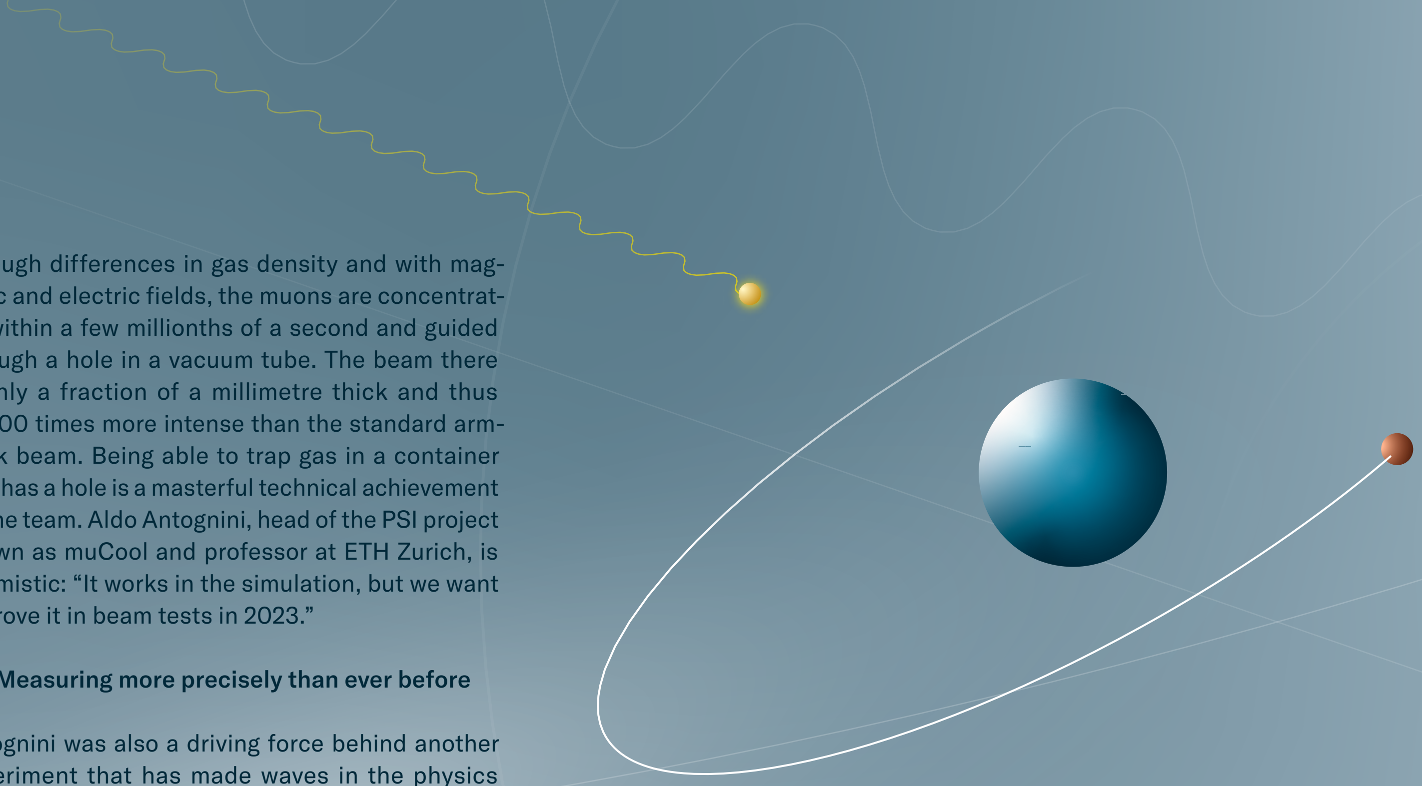
The experiments have to be carried out extremely quickly, however, because the anti-muon decays in two millionths of a second. If, contrary to expectations, it does not fall downwards with gravitational acceleration in the Earth's gravitational field, that would be more than a sensation – it would throw the general theory of relativity overboard. "I don't believe it will come to that," Klaus Kirch says, "but we can't afford not to shine a light into this very dark corner."

That only works if the flashlight is bright enough. For the researchers, that means they need to build ever more powerful machines with greater intensity and at the same time higher precision. In experiments searching for very rare events, statistics are everything.

It takes unimaginably large numbers of particles before such an event finally occurs. That's why PSI, together with the University of Zurich and the University Hospital of Zurich, proposed Project IMPACT for the Swiss Roadmap for Research Infrastructures for the 2025–2028 funding period. One of the two target stations at the proton accelerator envisioned in the project carries the designation HIMB, short for High-Intensity Muon Beam, capable of delivering ten billion muons per second for experiments. This could enable PSI to extend its world leadership in muon physics, just in time to present complementary results for comparison with results from the next phase of LHC operations at CERN near Geneva.

The ETH Board has now proposed the corresponding plan for the upcoming Swiss Roadmap for Research Infrastructures. The roadmap will be published in spring 2023, but a lot of preparatory work is already in full swing. One extension to HIMB would be a device that cools muons and improves beam quality a millionfold. The existing muon beam at PSI is to be slowed down in a chamber with very cold helium gas.

Through differences in gas density and with magnetic and electric fields, the muons are concentrated within a few millionths of a second and guided through a hole in a vacuum tube. The beam there is only a fraction of a millimetre thick and thus 10,000 times more intense than the standard arm-thick beam. Being able to trap gas in a container that has a hole is a masterful technical achievement by the team. Aldo Antognini, head of the PSI project known as muCool and professor at ETH Zurich, is optimistic: “It works in the simulation, but we want to prove it in beam tests in 2023.”



Measuring more precisely than ever before

Antognini was also a driving force behind another experiment that has made waves in the physics community: measuring the radius of the proton. Using the proton accelerator at PSI, his team produces muons that form muonic hydrogen, in which a negatively charged muon, instead of an electron, orbits the proton. PSI is the only research facility in the world that can produce sufficiently slow muons for such experiments. Muonic hydrogen is only 1/200th the size of hydrogen, so the energy levels of this atom are strongly influenced by the size of the proton. Exciting the resonant frequency between two energy levels in muonic hydrogen with a laser makes it possible to draw precise conclusions about the proton radius. At first, the PSI researchers found nothing. That’s because the 0.88 femtometre (1 femtometre = 1 millionth billionth metre) reading that earlier scattering experiments with electrons had given for the radius did not seem to be correct. Instead, the measurements levelled off at 0.84 femtometre. Many researchers from other institutes did not want to believe it, and questioned the finding from muonic hydrogen. Today, around ten years later, the waves have subsided and the smaller proton radius has been confirmed several times. The team has since measured the radius of deuterium and found a smaller radius there as well. The measurements of helium-3 and helium-4 have now been completed. There are no discrepancies, but the results obtained with muons are the most accurate of all.

In the first experiment, Antognini’s team measured the radius of the proton’s electric charge distribution. But the magnetic radius of the proton is also interesting. Determining this requires a special laser with high pulse energy and a specific wavelength, which has to fire within a millionth of a second when a muonic hydrogen atom is in the right position. Such a laser cannot be bought off the shelf, which is why the team is currently developing

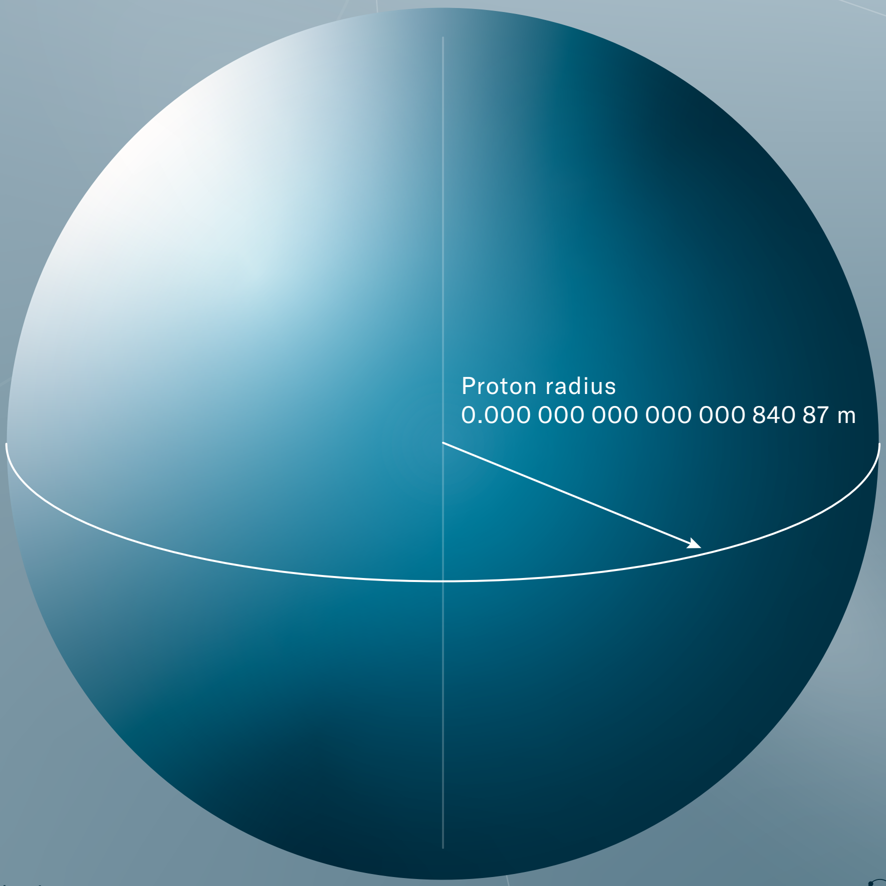
Physicist Aldo Antognini was involved, among other research efforts, in the most precise measurement to date of the proton radius, which caused a sensation around the world (see graphic right, and infographic, page 17).

one itself. The experiments are scheduled to begin in 2024. Here, too, it cannot be ruled out that older results will be tossed overboard.

Even though the plethora of experiments can seem confusing, they follow a master plan. “In particle physics, everything is interlinked,” Aldo Antognini says. “The whole structure has to be self-consistent.” For this, it is essential to have the natural constants under control. His experiments are making an important contribution towards this end. Knowing the proton radius as accurately as possible is the basis for determining the Rydberg constant, the most precisely measured fundamental constant in physics. This in turn is inherent in the SI units which are used to define the kilogram, metre and second, among other measurements.

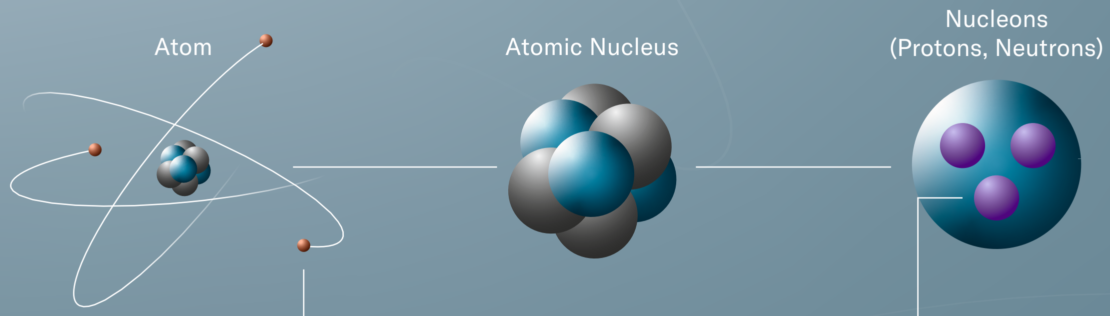
But are these constants really that constant? Researchers do not rule out the possibility that they will change over long periods of time. That would mean that in the dark room containing the radiant Standard Model of particle physics that we are familiar with, the walls are made of rubber and imperceptibly alter their form. Or even more radically: maybe there are other rooms in this museum – that is, other universes – in which other natural constants apply. “We can’t rule that out,” says Klaus Kirch. “That’s why we’re working on experiments to find out.” ◆

> “In particle physics, everything is interlinked. The whole structure has to be self-consistent.”
>
> Aldo Antognini, head of the muCool-project at PSI



The Standard Model of particle physics

Elementary particles are the smallest building blocks of nature. These are divided into two groups: matter particles and force particles. The latter mediate the forces between matter. The most familiar of these particles is the photon, which mediates the electromagnetic force. The gluon mediates the strong interaction. This prevents atomic nuclei from flying apart. The weak interaction is mediated by Z bosons and W bosons and is responsible for the fact that some nuclei decay. This creates radioactivity, for example. The Higgs particle is part of the Higgs mechanism, which says that all matter particles get their mass through interactions with the Higgs field. The building blocks of the atomic nucleus are made up of elementary particles, the protons and neutrons (see top right). Every elementary particle exists in two forms, as particle and antiparticle. This is one of the things that make the Standard Model of particle physics so difficult to understand. Ultimately all comparisons or images used to describe the Standard Model are workarounds. The model can only be completely described and understood in the language of mathematics.



MATTER
(Fermions)

Leptons

ν_e Electron Neutrino
Mass: < 1.0 eV/c²
Charge: 0 Spin: ½

e Electron
Mass: ≃0.511 MeV/c²
Charge: -1 Spin: ½

ν_μ Muon Neutrino
Mass: < 0.17 MeV/c²
Charge: 0 Spin: ½

μ Muon
Mass: ≃105.66 MeV/c²
Charge: -1 Spin: ½

ν_τ Tauon Neutrino
Mass: < 18.2 MeV/c²
Charge: 0 Spin: ½

τ Tauon
Mass: ≃1.7768 GeV/c²
Charge: -1 Spin: ½

Quarks

d Down
Mass: ≃4.7 MeV/c²
Charge: -⅓ Spin: ½

u Up
Mass: ≃2.2 MeV/c²
Charge: +⅔ Spin: ½

s Strange
Mass: ≃96 MeV/c²
Charge: -⅓ Spin: ½

c Charm
Mass: ≃1.28 GeV/c²
Charge: +⅔ Spin: ½

b Bottom
Mass: ≃4.18 GeV/c²
Charge: -⅓ Spin: ½

t Top
Mass: ≃173.1 GeV/c²
Charge: +⅔ Spin: ½

INTERACTIONS
(Bosons)

Vector Bosons

z Z Boson
Mass: < 91.19 GeV/c²
Charge: 0 Spin: 1

w W Boson
Mass: ≃80.39 GeV/c²
Charge: ±1 Spin: 1

Weak Interaction

γ Photon
Mass: 0
Charge: 0 Spin: 1

Electromagnetism

g Gluon
Mass: 0
Charge: 0 Spin: 1

Strong Interaction

? Graviton

Gravitation

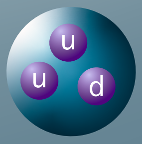
Scalar Bosons

H Higgs
Mass: ≃124.97 GeV/c²
Charge: 0 Spin: 0

Higgs Mechanism

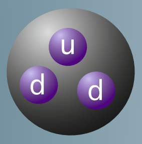
Antimatter

For every particle there exists an antiparticle with opposite charge.



Proton

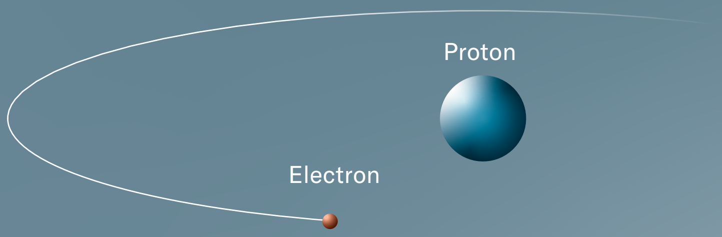
Charge +1 – consists of two up quarks (charge 2 × +⅔) and one down quark (charge -⅓) as well as a “sea” of gluons and quark-antiquark pairs. 99% of the mass comes from the strong interaction.



Neutron

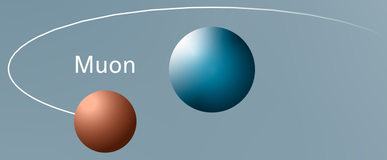
Charge 0 – consists of one up quark (charge +⅔) and two down quarks (charge 2 × -⅓) as well as a “sea” of gluons and quark-antiquark pairs. 99 % of the mass comes from the strong interaction.

Hydrogen



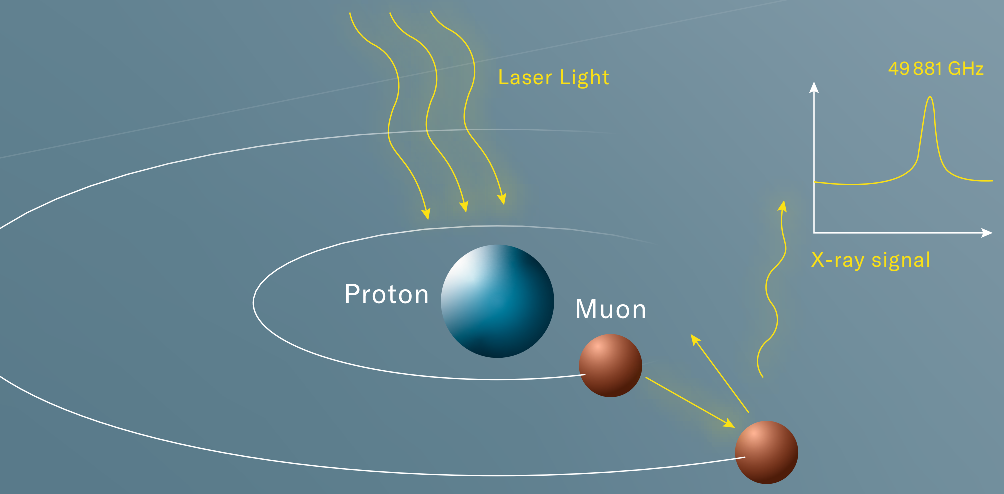
Muonic hydrogen

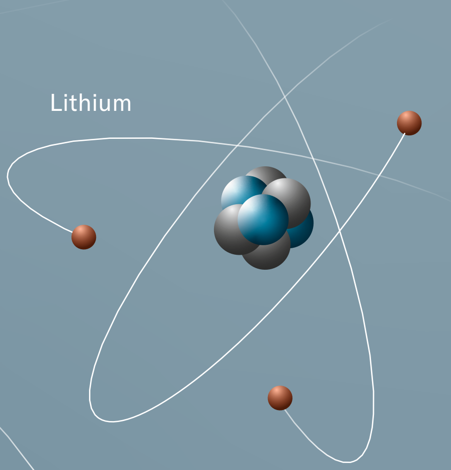
Consists of one proton and one muon:
- Lifetime circa 2 microseconds
- Diameter 1/186th of normal hydrogen

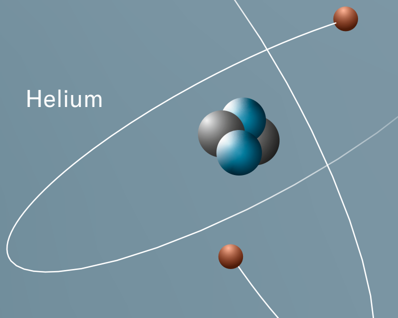


How PSI researchers are determining the proton radius

Muonic hydrogen is perfectly suited for determining the radius of the proton. The researchers replace the electron in the hydrogen atom with a negatively charged muon. They fire a pulse of light from an infrared laser at the muonic hydrogen. If the laser light has the right frequency, it raises the muon to a higher energy state. If it returns to its ground state, it emits X-rays that detectors can register. In the experiment, the laser frequency is varied until a large number of X-ray signals arrive; this is the resonance frequency. Here it is 49 881 gigahertz; from that, the difference between the two energetic states of the muon in the atom can be calculated. According to theory, this energy difference depends on the size of the proton. PSI researchers have also used this principle to determine the radius of the helium nucleus. To do this, they replaced one electron of the helium atom with a muon. Next up: lithium.







What can’t be bought, we develop ourselves

The work of PSI researchers is pushing the limits of knowledge and technological development. Many components for their experiments cannot simply be purchased. Then they just develop what’s needed themselves – and thus encourage many other applications in science or industry.

Text: Bernd Müller

Particle physics is complex and expensive. Large research infrastructures, such as the Large Hadron Collider (LHC) at CERN with its four detectors, cost billions. If researchers are asked what it’s all for, they have a few good answers ready. Above all, they say, it’s about gaining new insights, extending the boundaries of knowledge. In addition, in the large laboratories, thousands of skilled workers would be trained to use the latest technologies and work in interdisciplinary teams – a blessing for high-tech industry, and not only in Switzerland. Another argument: we are developing new technologies that could also be of interest for industrial applications.

With the development of the Domino Ring Sampler microchip, physicist Stefan Ritt created a masterpiece that is in demand around the world.

The latter is Stefan Ritt’s hobbyhorse. The PSI research group leader is both a physicist and an enthusiastic tinkerer. If an experiment at PSI requires a particular electronic circuit that cannot be purchased anywhere, he doesn’t hesitate to get out the soldering iron and build it himself. In this way he achieved a milestone ten years ago: DRS4. This “domino ring sampler” is a microchip that, simply put, integrates an ultrafast oscilloscope on a surface the size of a fingernail. The temporal resolution is less than ten trillionths of a second. This enables researchers to detect particles produced by muon decay processes. The high temporal resolution and enormous speed of the chip are necessary because, in these experiments at PSI, 30 million such decays take place every second, and their signals overlap. That’s what makes the analysis so tricky.

One of the most loyal “customers” is Aldo Antognini with his experiments to determine the proton radius (see page 14). But he’s not the only one: numerous research laboratories around the world use the DRS4. For example, medical researchers in Tübingen, Germany, use it to localise brain tumours with pinpoint accuracy. Ten thousand units of the DRS4 have already been sold. Due to such high demand, the chips are now manufactured in Taiwan and sold by RADEC GmbH, a PSI spinoff based in Koblenz, Switzerland. The company of the former PSI physicist Radoslaw Marcinkowski provides services for space missions, excellent proof that PSI know-how is valued and put to use far beyond its gates.

In use worldwide

But one thing is important to Stefan Ritt: “We don’t pursue commercial interests. We sell the chips and the associated electronics boards at cost." The research mission of PSI always comes first. This also applies to the electronics and software that Ritt's team is currently developing for new, very fast particle detectors. In the future, Ritt would also like to improve the DRS4 chip so that the data can be read out even faster.

Even if PSI develops hardware and software mainly for its own research purposes, that doesn't mean this research has to take place on its Villigen campus. PSI researchers are also involved in collaborations at other research centres, especially CERN in Geneva. With the large proton accelerator LHC, this provides the infrastructure, while on the other hand the detectors CMS, ATLAS, LHCb, and ALICE are operated by international consortia. At CMS alone, around 200 research institutes from around the world are involved, with more than 5,800 researchers, administrative staff, and technicians. Each partner contributes a part to the detector and its operation, and in return may use the data.

One immensely important component of CMS, which is as big as a multifamily residential building and weighs 12,500 tonnes, is the silicon pixel detector. It sits deep inside CMS and is comparatively small, but it fulfils an important function. By analysing the charged particles created during proton collisions, it measures the location where each collision took place with micrometre precision. This location is the basis for the measurements of the other detectors surrounding the silicon pixel detector – which was developed and built at PSI – like layers of an onion.

In principle, the detector is a digital camera with 124 million pixels, 150 by 100 micrometres, measuring not light but rather charged particles – 40 million times per second. The first detector, which went into operation with the LHC in 2008, consisted of three cylindrical layers; the second evolutionary stage, with four layers and faster electronics, is now in operation.

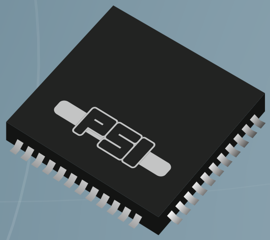
For the next stage in the expansion of the LHC, planned to start in 2029, even this detector is much too slow. The LHC's luminosity – its brightness, you could say – will increase fivefold, and CMS will have to process a correspondingly larger number of particle collisions. For this third generation of the pixel detector, Lea Caminada, head of the ten-person high-energy physics group at PSI and professor at the University of Zurich, came up with something new: the Tracker Extended PiXel System. TEPX is designed to cover a still larger solid angle and should also register particles that fly forwards or backwards in approximately the direction of these beams. That is important because certain exotic particles – including the famous Higgs particle – exhibit signatures that can only be measured at those locations, and are currently not covered. Because the surface area of the detector will be much larger and twice as many modules will be installed, the team is developing a robot to automate assembly.

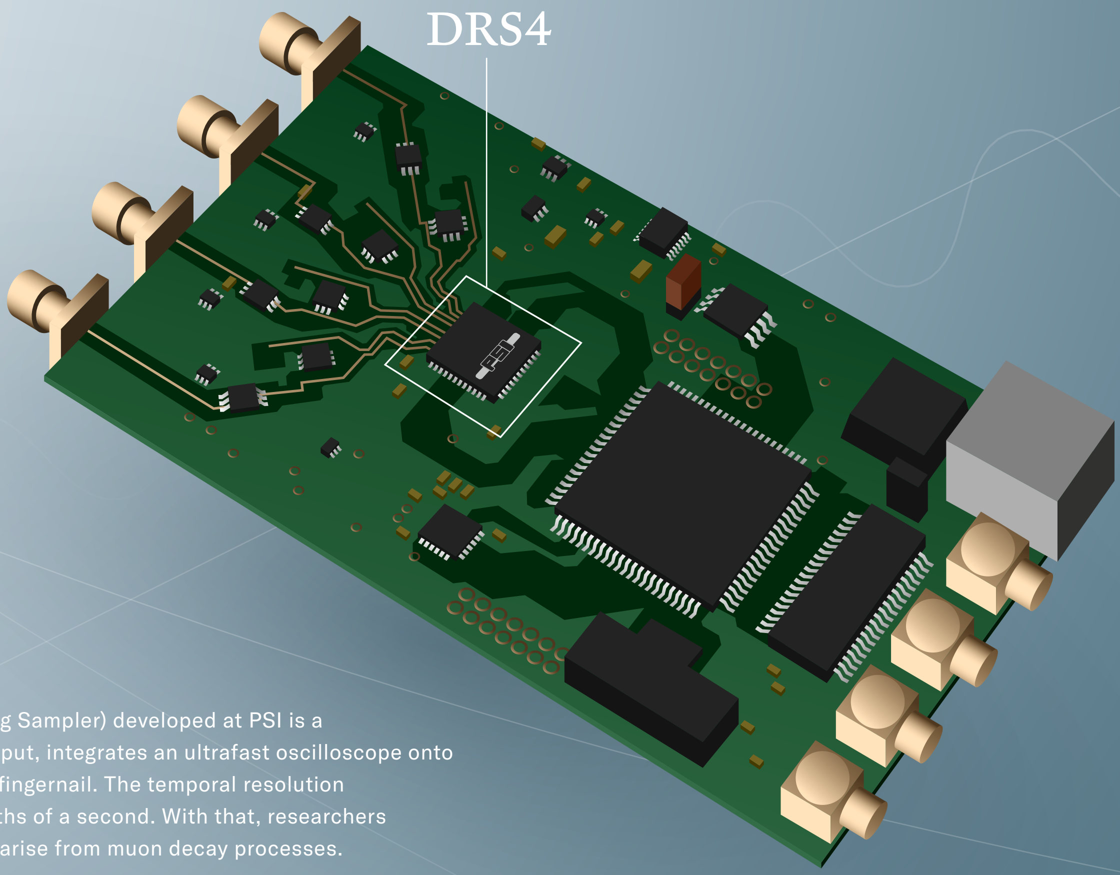
Physicist Lea Caminada is developing a new generation of pixel detectors to make even better measurements possible.

The Swiss economy benefits

The in-house development of pixel detectors also benefits other research fields, such as muon spin spectroscopy. This can be used to determine the magnetic properties of materials, including some

> "We sell the chips and the associated electronics boards at cost."
>
> Stefan Ritt, research group leader at PSI





The DRS4

The DRS4 (Domino Ring Sampler) developed at PSI is a microchip that, simply put, integrates an ultrafast oscilloscope onto a surface the size of a fingernail. The temporal resolution is less than ten trillionths of a second. With that, researchers can find particles that arise from muon decay processes.

that might be used to build future quantum computers. In a magnetic field, the material is bombarded with muons, which decay into positrons within microseconds. From the temporal distribution of the positrons, the researchers can deduce the magnetisation of the material. Up to now, this has only been possible if the muons arrive one after the other. PSI's fast detector would allow the simultaneous measurement of many muons, which would multiply the measurement rate and deliver a three-dimensional image of the magnetisation inside the material.

Such an apparatus could also be of interest for industrial applications. Christian Brönnimann, former doctoral researcher at PSI and founder of the PSI spinoff company DECTRIS AG in Baden-Dättwil, co-developed the first silicon pixel detector for CMS and made it into a commercially successful product. The DECTRIS detectors are at the forefront of X-ray analysis. One specialty of the company is hybrid detectors that can simultaneously count electrons as well. "Through the fundamental research at PSI, positions for 100 highly qualified workers have been created," Brönnimann says. DECTRIS and PSI are still working together today. Lea Caminada: "We support each other with know-how in the development and construction of new detectors. Our research profits from this, and so does the Swiss economy." ◆

> "Our research profits from the mutual support, and so does the Swiss economy."

Lea Caminada, research group leader at PSI
and professor at the University of Zurich

Focusing neutrons

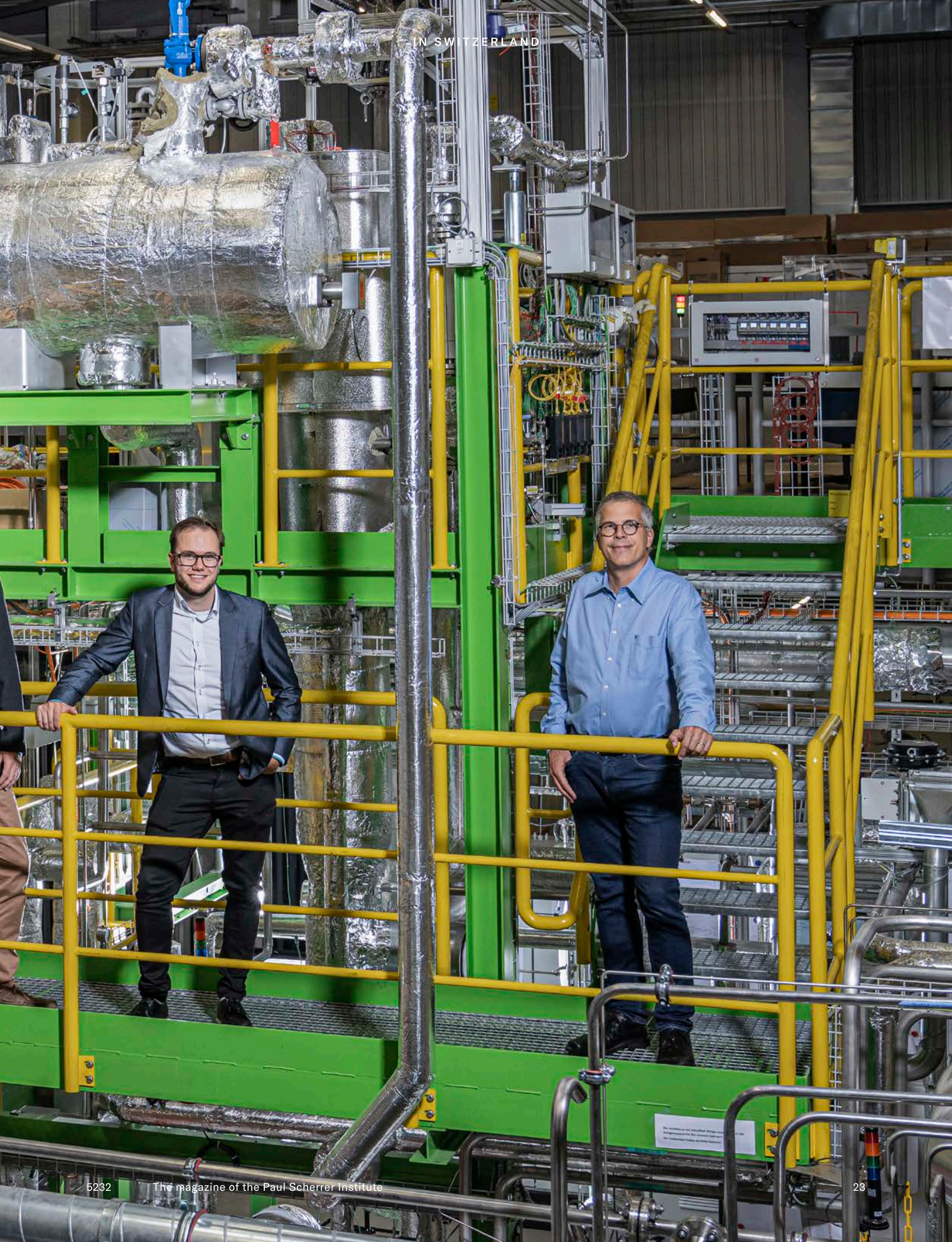
Physicist Artur Glavic develops novel instruments for large research facilities that allow researchers to analyse thin layers and interfaces of materials with neutrons. The neutron reflectometer he is currently realising consists of two elliptical neutron mirrors, 7 metres in size, installed in series. The reflectometer is able to focus on samples just one square millimetre in size. Compared with existing reflectometers, the intensity of the beam is up to 30 times greater, producing images with significantly higher resolution. This year, Artur Glavic received the Instrumentation Prize of the Research with Neutrons Committee in recognition of his extraordinary achievements in construction and development.

Methane as an energy store

One important question regarding the planned transition to supplying energy without greenhouse gas emissions is: How can we store energy for times when wind turbines and photovoltaic systems are not supplying electricity? Researchers at the Paul Scherrer Institute and the start-up AlphaSYNT offer one possible answer. With a new approach to “power-to-methane” conversion, they are promoting a technology for storing energy in the form of methane gas that is ready for industrial use.

Text: Benjamin A. Senn

Andreas Aeschimann and Luca Schmidlin from AlphaSYNT, and Tilman Schildhauer from PSI (left to right) in front of the GanyMeth pilot plant at PSI. In the future such systems are to be built by AlphaSYNT for biogas or wastewater treatment plants to store energy in the form of methane gas.



Let's take the following imaginary scenario: It's the year 2050. As part of a charity event, and at the urging of his fans around the world, Roger Federer, now 69 years old, ventures onto the court again to compete in a "friendly game" against his long-time rival Rafael Nadal. A global event that will be broadcast live from the St. Jakobshalle arena in Basel to domestic and international screens, as well as countless public venues throughout Switzerland. It's a muggy Saturday afternoon in July, loads of drinks are being chilled, and air conditioners are running full blast. The sky is overcast, and there's no wind.

The weather conditions are probably not ideal for Roger Federer, who is no longer quite so young, to engage in high-performance sport. The oppressive atmosphere could also cause problems for the viewers. In 2050 there will no longer be any nuclear power plants connected to the grid in Switzerland, and renewable energy sources such as wind and solar power will make a vital contribution to our electricity supply. But when the sun doesn't shine and the wind doesn't blow, the screens could go black and the biggest TV event of the year could be cancelled.

Granted, this scenario seems a bit contrived, but the underlying problem is red hot. Storing energy from renewable sources in a sensible way, so that it can be fed into the grid outside of peak production times, is a challenge that is being intensively investigated – including at PSI.

Use the existing infrastructure

For almost ten years, the Laboratory for Bioenergy and Catalysis at PSI has been developing processes to cleanly and efficiently convert biomass from agricultural and forestry waste into gaseous or liquid combustibles or fuels. This concept, called power-to-gas, envisages using excess renewable electricity to produce hydrogen and, in a second step, converting it into synthetic natural gas.

The first step occurs through a process called water electrolysis, where water is split into hydrogen and oxygen. This converts the electrical energy into a chemical energy carrier, hydrogen.

"With the help of fuel cells, hydrogen can be converted back into electricity," explains Tilman Schildhauer, scientific lead on methanation and industrial power-to-X at PSI. These cells are very powerful and clean. Because they do not require combustion, the only by-products are heat and water. "However, the production costs are very high. In addition, hydrogen is a light gas that requires an enormous storage volume. Switzerland still lacks the necessary infrastructure to use hydrogen sensibly."

Methane is a different story. This colourless and odourless gas takes up only a third of the volume of hydrogen with the same energy content, and it can already be stored and distributed using the same infrastructure as natural gas. That's why Tilman Schildhauer and his team are focusing on using the hydrogen obtained through electrolysis to synthesise methane in a second step.

From hydrogen and carbon to methane

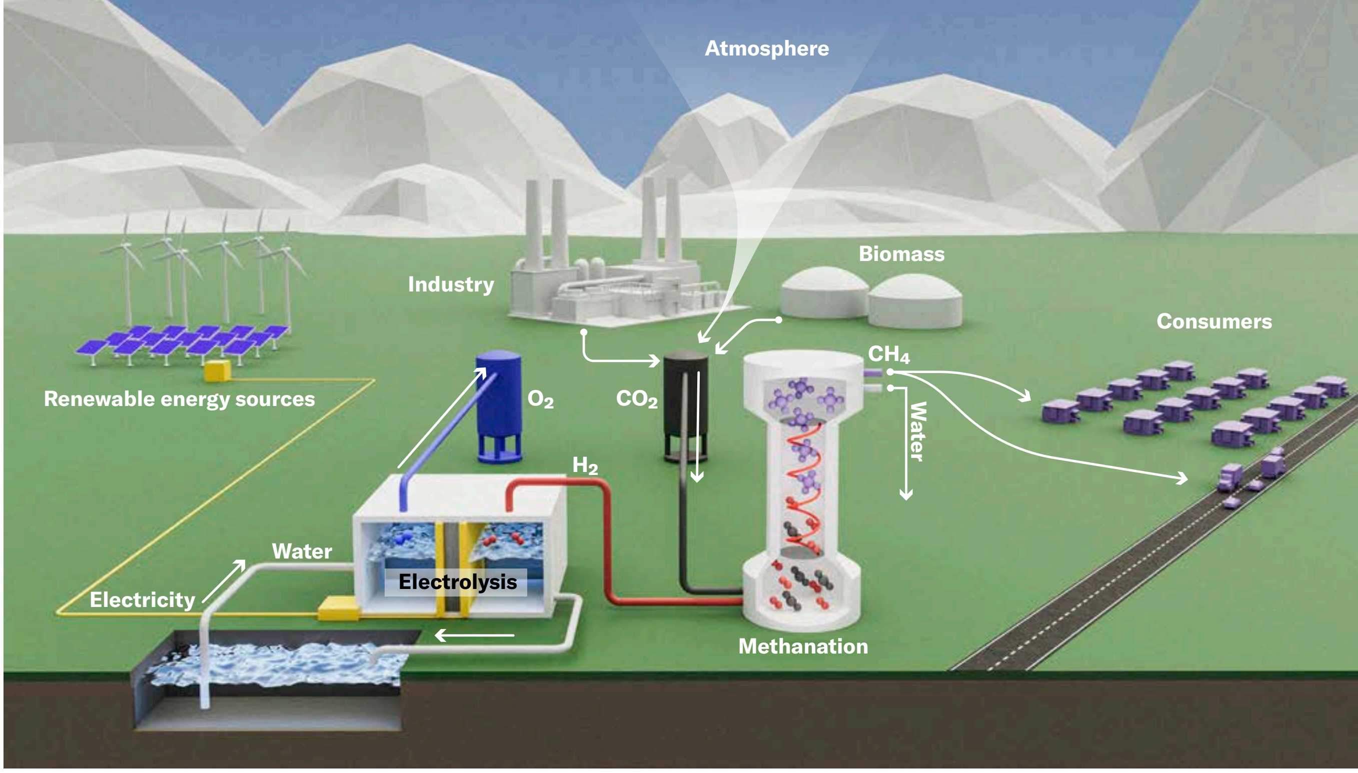
Back in 1902, the French chemists Paul Sabatier and Jean-Baptiste Senderens discovered the reaction of carbon dioxide and hydrogen to form methane and water. Since this discovery, many different processes have been developed to make this reaction as efficient as possible. For their methanation process, researchers at PSI have developed a fluidised bed reactor, which contains fine nickel particles as a catalyst. When the carbon dioxide and hydrogen are fed in, the particles are swirled around and converted into a fluidised state by the upward flow – so the reaction is continuous.

Besides methane and water, this reaction also produces high temperatures. To maintain the process and achieve a high throughput, the mixture must be cooled down to the optimal reaction temperature. Tilman Schildhauer and his team have devised a special trick to resolve this: "We use a pipe system that allows oil to flow through our reactor. The oil absorbs the heat inside the reactor and releases it outside – just like a refrigerator," Tilman Schildhauer explains. This construction, combined with the fluidisation of the particles, allows especially efficient cooling, resulting in an isothermal, compact and low-cost reactor.

This reactor can now be used, for example, in biogas plants. Biogas is produced by fermenting biomass such as liquid manure, plants, or sewage sludge, and consists of about two-thirds methane and one-third carbon dioxide. For this gas mixture to be used effectively in the gas network, it must have a certain level of purity – at least 96 percent methane content. "The gas mixture is fed into our fluidised bed reactor together with the hydrogen obtained, and the carbon dioxide reacts to form additional methane," says Tilman Schildhauer.

The step from laboratory to industry

The technology works, and with GanyMeth a first pilot reactor was built and tested at PSI (see pages 22/23). The task now is to implement the methanation process in industry. To this end, PSI has joined forces with the start-up AlphaSYNT. Together they want to take the new approach to market, though not for private households – the technology is too



Schematic view of the value chain: electrolysis splits water (H_2O) into oxygen (O) and hydrogen (H_2). In the methanation stage, the hydrogen reacts with carbon dioxide (CO_2) to produce methane (CH_4), which is then supplied to consumers.

complex for that. The main target market is larger energy suppliers that own biogas plants, which could profit from this technology.

AlphaSYNT was founded as a start-up in 2020 by Andreas Aeschimann (CEO) and Luca Schmidlin (CTO). A chance conversation during a coffee break at a measurement technology seminar grew into a strong partnership with a common goal. "*Alpha* stands for the beginning. We both wanted to be at the forefront, taking a chance and investing to help shape and advance the transformation of the energy system. Luca and I hit it off right away," Andreas Aeschimann recalls. "The technology from PSI is ready to use. Thanks to our business and technical know-how, we can now achieve this goal."

With the commercialisation of the methanation process developed at PSI, fossil gases should be successively replaced by renewable methane gas. "The flexible storage of surplus electricity from renewable sources in the summer will also help to stabilise the power grid," explains Andreas Aeschimann.

Looking towards the future

It's not only biogas plants that can benefit from partnership with AlphaSYNT and PSI. The technology works with carbon dioxide from any source. It could be captured directly from ambient air, for example, or could come from wastewater treatment plants, waste incineration plants, cement works, or plants with wood gasification. For the latter, AlphaSYNT and PSI were awarded a contract to construct a methanation plant in Portugal in May 2022.

The pilot reactor is part of PSI's Energy System Integration Platform, ESI for short. Here PSI, in close collaboration with AlphaSYNT and other partners from research and industry, is looking into the technical and economic feasibility of different variants of power-to-gas technology.

So nothing should stand in the way of our fictitious future tennis match – it would all come down to the motivation of Roger Federer and his possible opponent, Rafael Nadal. ◆

Latest PSI research news

535 million years is the age of the stone in which the fossils were found.

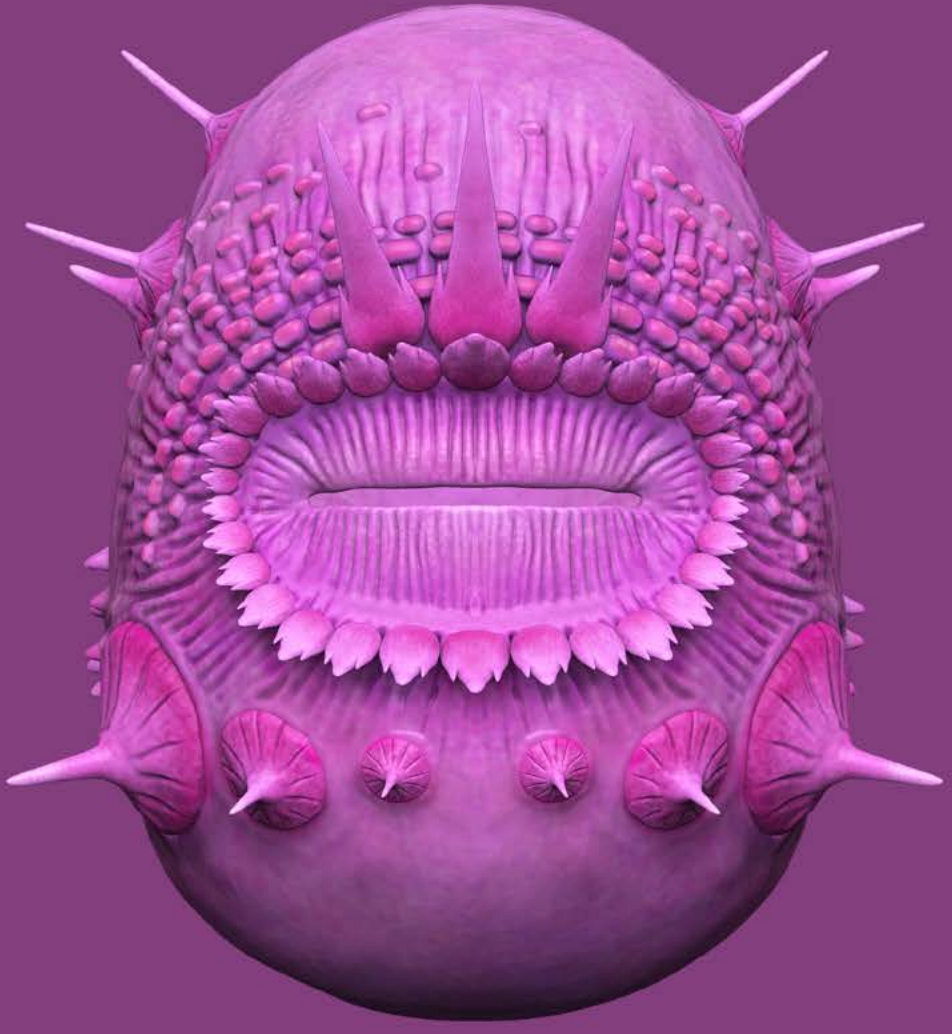
1 millimetre is the approximate diameter of the fossils.

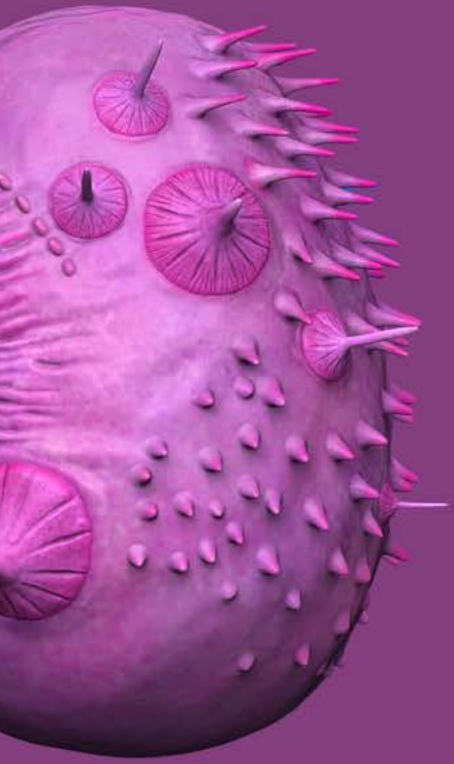
2017 is when the now-disproven hypothesis was proposed.

1 Weird fossil is not our ancestor

A recent hypothesis suggested that humans' evolutionary roots reached back to a strange, microscopically small creature with a mouth but no anus. Thanks to analysis of fossils at the Swiss Light Source SLS, we now know this isn't true: *Saccorhytus* is not a *deuterostome* like us, but an *ecdysozoan.* This peculiar-looking fossil, resembling a spiny, wrinkled sac, has a spiked mouth and holes that were interpreted as gill pores. It is precisely those supposed gill pores that put researchers on the wrong track. New investigations at SLS revealed these to be the bases of spines, and the fossil could be struck off the human family tree.

Further information:
http://psi.ch/en/node/52886





2 Making tumour diagnosis kinder to kidneys

Researchers at PSI, in collaboration with ETH Zurich, have optimised a method for diagnosing tumours using radionuclides. A molecular trick makes it possible to significantly reduce potential side-effects. To achieve this, the researchers modified a molecule that can detect a tumour. This molecule contains both a specific binding structure for tumours and a radionuclide. If the molecule docks onto a tumour, the radionuclide can be detected. If it gets into the kidneys instead, it is split apart there – thanks to the molecular trick. Then the radionuclide is directly excreted from the body via the urinary tract. This significantly reduces radioactive deposits in the kidneys. Radionuclides are unstable atoms that spontaneously decay, releasing high-energy radiation. The researchers hope that their findings can also be used for other radiopharmaceuticals that are associated with similar side-effects.

Further information:
http://psi.ch/en/node/53842

3 Nanomaterial from the Middle Ages

To gild sculptures, artists in the late Middle Ages often applied an ultra-thin gold film supported by a silver base layer. This so-called Zwischgold was significantly less expensive than conventional gold leaf, since its gold layer was much thinner. There are no records from the time, however, that indicate how Zwischgold was made. Now PSI researchers have, for the first time, made three-dimensional nano-images of it. The images show how highly developed the medieval production technology was. First the gold and silver were separately hammered into foils, and the gold layer had to be much thinner than the silver. Then the two metal foils were further processed to join them together. The examinations of Zwischgold samples showed the average thickness of the gold layer to be around 30 nanometres, while gold leaf made in the same period and region was around 140 nanometres thick. The results could aid in the development of new techniques for the conservation of old works of art.

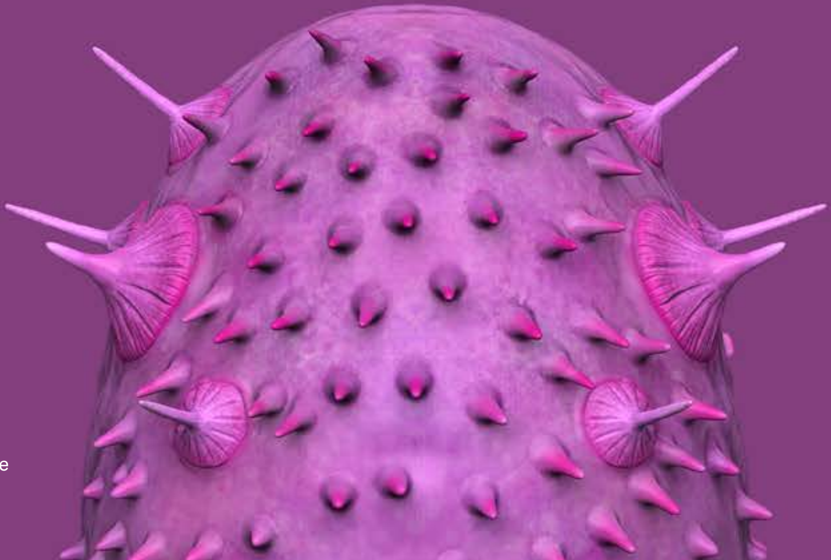
Further information:
http://psi.ch/en/node/53727

4 Outstanding PSI electronics technicians

At the professional championships in the field of electronics, two young electronics technicians from PSI received the two top medals: in the nationwide SwissSkills 2022 competition, Melvin Deubelbeiss took first place. At the WorldSkills 2022 championships, which took place shortly afterwards, Mario Liechti won the silver medal for Switzerland – and unofficially for PSI. Both electronics technicians learned their profession at PSI, in the Research with Neutrons and Muons Division. These gold and silver medals show that PSI is attractive to talented young people and can give them both stimulating tasks and excellent training.

WorldSkills competitions are held in 62 disciplines: from car painting to floristry, cooking and web technology, young people compete against each other in their respective skills. The competitors must not be older than 22 or 25, depending on the discipline. SwissSkills is a national organisation that promotes young professionals and enables them to take part in international championships such as WorldSkills.

Further information
http://psi.ch/en/node/53619
http://psi.ch/en/node/54278



Different perspectives

At PSI, researchers look deep inside matter and materials using large research facilities that are, to some extent, unique. The detail this enables them to see, down to the tiniest thing in existence, usually has little in common with what can be seen with the naked eye. In this gallery we play with the contrast between large and small as we lead you past the facades of the Paul Scherrer Institute.

Text: Christian Heid

Galactic nebula

Maybe this is how galactic nebula might look … Others see a white ski slope or cooled lava coming from the lower right edge of the picture over a precipitous drop and a little wave through a brownish, milky-hazy mountain landscape to the other side. Still others think of a detail of tissue on an X-ray. But in fact this picture shows a section, beautifully staged in the small photo, of the marbled entrance portal of the X-ray free-electron laser SwissFEL. This latest of PSI's large research facilities generates very short pulses of X-ray light with laser-like properties. Researchers can use it, for example, to track extremely fast processes such as the creation of new molecules in chemical reactions.

Bread crust

This mouth-watering "bread crust" with finely distributed oat flakes, and with a dark, bewildering labyrinth of fissures burned into it by the baking process, is in reality not so tasty: the picture actually shows roofing material that protects the UFO-shaped building of the Swiss Light Source SLS, on the west side of the PSI campus, from rain, wind and sun. Here on the sunny side of the building - in contrast to the shadier side - the sun's rays have created the kind of appearance that sunburned, aged skin can exhibit. With the synchrotron light of SLS, an especially intense kind of X-ray light, protein structures can be deciphered, for example, or the distribution of an element in an alloy can be rendered as 3-D images. The facility is undergoing an update, and by 2025 the quality of the X-rays it generates for research will be improved 40-fold.

Moonscape

This picture could represent the view from an approaching moon lander or some other bluish-tinted relief with craters, belonging perhaps to an alien celestial body. In that case, the day-night boundary, the so-called terminator or separator, would be plain to see. But the apparent day-night boundary is in fact a flowing colour gradient from dark to light blue in brand new graffiti on the facade of our visitor centre, the psi forum. The redesigned, publicly accessible exhibition is a portal to the world of science. Here visitors can be fascinated by the exhibits and find out what topics scientists are investigating at PSI.

Dragon fruit

The fruits of many cactus plants have a rough, forbidding surface comparable to the metal grille that encloses an air conditioner on the back side of the auditorium. Completely in contrast to its botanical, optically similar counterpart, though, this facade is not meant to repulse, but rather to invite visitors into exchange and dialogue. The auditorium is, among other things, a place where researchers come together with scientists from other research institutions to exchange ideas and information about their research worlds. Other internal and external events also take place here, for example when international delegations or national politicians visit the Institute.

Fossil

This object could also be a clue to primeval life: the fossil of a tree trunk. Yet this is not a matter of mineralisation; no organic elements have been converted into inorganic compounds here. This idea readily suggests itself, though, because it actually does involve the annual growth rings of a tree, which have been transferred from a wooden mould to this concrete surface.Behind this concrete wall is a linear accelerator, the so-called Cockcroft-Walton accelerator, which is the source of PSI's proton beams. The protons are used, on the one hand, for fundamental research, materials analysis and cancer therapy. With their help, on the other hand, neutrons, muons and pions are generated, which then can be used as probes to gain insights into materials and processes.

Hearty, but sophisticated

An apprenticeship in Oase, PSI's staff restaurant, gave Michaela Frank the basis for her career as one of the youngest top chefs in Switzerland. The Aargau native became Vice Olympic Champion with the national junior culinary team and has competed successfully in numerous individual competitions. Today the 26-year-old is head chef at Kultur Lokal Rank in Zurich.

Text: Barbara Vonarburg

At 10 in the morning cleaning is under way at the restaurant Rank on Niederdorfstrasse in Zurich's old town. Before work begins for lunch, Michaela Frank offers a tour. "Here, where we have our tables and the concert stage, used to be a strip club called Calypso," she says. "And at a take-away counter you could get a currywurst that was famous throughout the city." Now renovated, it houses a restaurant serving imaginative dishes made from local products and selling toasted sandwiches to take away. Its motto: "A contemporary Zurich kitchen connected to its roots and inspired by the world. Hearty, exciting, and benevolent."

Michaela Frank pulls aside a curtain. This gives guests a clear view into the area where the young chef and her team of five work. The curtain is only closed on evenings when musicians from the Swiss jazz scene play here, from Thursday through Saturday, so the kitchen won't draw attention away from the concert. Rank is more than a restaurant. It sees itself as "a meeting place for art and culinary arts. A fusion between gastronomy and jazz club" – a concept that appealed to Michaela Frank right away. That's why she decided to take up the position of head chef in the newly opened restaurant in October 2021.

PSI – a stroke of luck

As a student growing up in Nussbaumen in the canton of Aargau, she approached various restaurants in the area looking for an apprenticeship. She always got the same advice: "Go to PSI." "I had no idea why, but I went there and got the apprenticeship," she recalls. "A stroke of luck, because the PSI staff restaurant had – and still has – a very good reputation." Christian Wandres, current manager of the PSI restaurant Oase, was then its head chef and served as master to apprentice Michaela Frank. Then-manager Franz Jonke and Doris Vögeli, currently head chef at PSI, have won several international competitions with their culinary skills. "Doris Vögeli was my mentor and made many things possible for me," Frank recalls.

The supervisors recognised their trainee's talent and assured her their support if she wanted to take part in cooking competitions. Yes, she did. "I love challenges," Frank says. "These competitions gave me a goal I could work towards." After completing her apprenticeship, she gained a place in the junior national culinary team, and with it she won the title of Vice Olympic Champion. "As a child in school I was rather quiet and reserved," she says. "My Asian roots were my most striking feature." But when she was cooking, she realised, "This is what I want to do." Her success in the competitions showed her in a new light, and that gave her an additional confidence boost.

Even afterwards, she was allowed to use the PSI kitchen for test runs before cooking competitions. And today she still comes and goes to the Oase restaurant as a guest. She likes to remember her apprenticeship and tells with a smile how she prepared 100 kilograms of spaetzle herself: "After I had made the dough, I went to the huge tilting kettle and the enormously long sieve with the holes. Then I pushed the spaetzle through the sieve with the dough scraper, which was like a workout for me because I'm rather small."

The leap into gourmet cuisine

From today's perspective, she had what might be called a 'cushy' job in the staff restaurant, with regulated hours unlike any other restaurant kitchen. "It was a framework in which I had good support and

> “My apprenticeship was a stroke of luck because the PSI staff restaurant had and still has a very good reputation.”

Michaela Frank, head chef at Kultur Lokal Rank

learned a solid foundation," Frank says. The food for the PSI staff had to be tasty, hot, and attractive. "We didn't serve anything below our high standard," she says. Nevertheless, it was a great leap she made immediately after completing her apprenticeship when, in 2015, she took up a position as a chef in a five-star hotel in Flims and later worked at the Park Hotel Vitznau, when its chef, Nenad Mlinarevic, had just been voted chef of the year.

Yet the moment came when Frank questioned her commitment to gourmet cuisine and the junior national culinary team. "I had a knock-back," she says. "I started arguing with myself, which I had never done before, and realised that I also needed to start living a little." She gave up the competitions and worked as a barista for a while. "Dealing with coffee turned out to be fun, but the job wasn't what I'd been looking for," she says. She decided to trace her roots in China. In Shanghai, she acquired a language certificate, but she quickly felt how foreign China was to her. She continued to travel through Asia, returned to Switzerland, and still didn't know what her future should look like until she recalled the joy of her former job.

"I wanted to experience that again, with the gourmet and haute cuisine, and I applied for a grant from the Uccelin Foundation," Frank says. This foundation was established by star cook Andreas Caminada to promote young gastronomic talent. The scholarship holders can work for 20 weeks in various top operations in Switzerland and abroad. Frank received the Uccelin scholarship. In October 2019, she started with Caminada in Fürstenau, in the canton of Graubünden. Then, in two specialty bakeries in the canton of Lucerne, she learned how to bake particularly tasty bread, and she learned what it takes to produce pralines working with a chocolatier in Belgium.

Tear gas in Chile

Other career stations included the renowned "Stucki" in Basel as well as various restaurants in Istanbul and Santiago de Chile. "In Chile, nothing went as planned," says Frank. An increase in the price of subway tickets triggered a wave of demonstrations in November 2015. "The gap between rich and poor in Chile is extremely large," she explains, which made the protests understandable but also frightening. "I often got into a demonstration that I had to cross to get home." Fortunately, nothing ever happened to her, except that tear gas irritated her eyes and skin. But she also brought home with her a "super cool" tip from a Chilean chef. He noticed that the kitchen floor around her was not clean and rebuked her: "I don't care what's on your CV. If your floor is dirty, you can't work for me." Frank is convinced that the workplace actually does say more about a person than their qualifications.

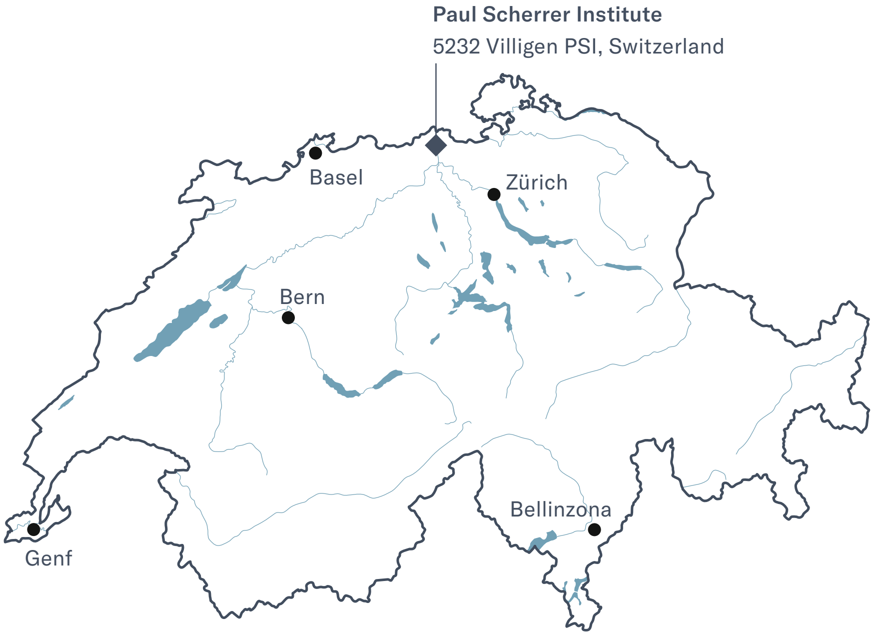
After the scholarship ended, the coronavirus lockdown followed in spring 2020. Frank had returned from abroad and was enjoying the break after the hectic time. "For many this was a difficult phase," she is aware: "I enjoyed staying at home, and I cooked for my parents every day." But soon she was working again in a top restaurant and decided to train as a chef. "It was a special experience going back to school," she recalls: "When you're cooking, the pace is very quick, it's intense, you have to master the craft and be fast. I had to regain my concentration while studying." She passed her final exam, realised various projects with her own catering outfit, and finally decided to head the kitchen team in the Rank restaurant.

Lots of vegetables and a little meat

One dish on the menu that's close to Frank's heart is congee, a Chinese rice dish. "This is the canvas for all the vegetables that we get fresh from producers in the region," she explains. Sustainability is important to her. That's why the menu often includes dumplings, to use up bread left over from making the toasted sandwiches. She rarely cooks meat. Describing her cuisine, she says, "The dishes showcase vegetables mainly, but with a certain refinement. It's not fine dining at the highest level. People should simply get something good to eat, feel good, and come back every week."

She wants to stay at Rank in Zurich's old town for a few more years and gain experience. "At some point the perfect moment will come to move on, but there is still a lot to discover here," she says with a laugh. She's already certain: "When the time comes, it will be good." ◆

From our base in Aargau
we conduct research for Switzerland
as part of a global collaboration.



5

large research facilities that are unique in Switzerland

800

scientific articles a year based on the experiments performed at PSI's large research facilities

5,000

visits every year from scientists from across the globe who perform experiments at our large research facilities

5232 is Switzerland's prime address for experiments on large research facilities. The Paul Scherrer Institute PSI even has its own postcode, a distinction that seems justified for an institute that extends over 342,000 square metres, has its own bridge across the River Aare, and has around 2,200 employees – more people than in most of the surrounding villages.

PSI is situated on both banks of the River Aare in the canton of Aargau, in the municipal areas of Villigen and Würenlingen. Its main areas of research are in the natural sciences and engineering. Funded by the federal government, it belongs to the domain of the Swiss Federal Institute of Technology (ETH Domain), which also includes ETH Zurich, EPFL Lausanne, and the research institutes Eawag (Swiss Federal Institute of Aquatic Science and Technology), Empa (Swiss Federal Laboratories for Materials Science and Technology) and WSL (Swiss Federal Institute for Forest, Snow, and Landscape Research). We conduct basic and applied research and thus work on sustainable solutions for central questions from society, science and business.

Complex large research facilities

Switzerland's federal government has given PSI the mandate to develop, build, and operate large, complex research facilities. These are the only such facilities within Switzerland, and some are the only ones in the world.

Running experiments at our large research facilities enables many scientists from the most diverse disciplines to gain fundamental insights for their work. The construction and operation of these kinds of facilities involve so much time, effort, and cost that comparable measurement equipment is not available to academic and industrial research groups at their own institutions. That is why we keep our facilities open to all researchers worldwide.

To obtain a time slot to use the experimental stations, however, both Swiss and foreign scientists first have to apply to PSI. Selection committees comprising experts from all over the world assess the scientific quality of these applications and recommend to PSI which candidates should be given measurement time. Even though there are around 40 measuring stations where experiments can be carried out at the same time, there is never enough capacity for all of the proposals submitted – around one-half to two thirds have to be rejected.

Around 1,900 experiments are performed every year at PSI's large research facilities. Time slots are free of charge for all researchers working in academia. In a special process, users from private industry can buy time to carry out proprietary research and use the PSI facilities for their own applied research. For this, PSI offers special research and development services.

PSI operates five large research facilities in total where the internal processes of materials, biomolecules, and technical devices to explore the processes taking place inside them. Here scientists use different beams to "illuminate" the samples they want to investigate in their experiments. The beams available for this range from particles (neutrons or muons) to intense X-ray light from a synchrotron or X-ray laser source. The different types of beams allow a wide variety of material properties to be studied at PSI. The high complexity and cost of the facilities is due to the massive size of the accelerators needed to generate the different beams.

Four main areas of research

However, PSI not only acts as a service provider for researchers, but also carries out an ambitious research programme of its own. The findings produced by PSI scientists help us to understand the world better, and also lay the foundation for developing new types of equipment and medical treatments.

At the same time, our own research is an important prerequisite for the success of our user service programme for the large research facilities. Only researchers personally involved in current scientific developments in the fields external researchers are working in can support them in their investigations and further refine the facilities to ensure they continue to meet the needs of cutting-edge research in the future.

Our own research is concentrated on four focus areas. In the area of Future Technologies, we investigate the diverse properties of materials. With the knowledge this yields, we create the foundations for new applications – whether in medicine, information technology, energy production and storage, or new industrial production methods.

The goal of our work in the focus area Energy and Climate is developing new technologies for a sustainable and safe energy supply, as well as for a clean environment. Also in this area, we are investigating interconnections within Earth's climate system.

In the focus area Health Innovation, researchers are looking for the causes of diseases as well as for potential therapeutic methods. In addition, we operate the only facility in Switzerland using protons for the treatment of specific cancer diseases. This special technique makes it possible to destroy tumours in a targeted way while leaving the surrounding health tissue largely undamaged.

In the area Fundamentals of Nature, researchers are seeking answers to fundamental questions about the basic structures of matter and the functional principles of nature. They investigate the structure and properties of elementary particles – the smallest building blocks of matter – or clarify fundamental processes in living organisms. The knowledge gained in this way opens up new approaches to solutions in science, medicine and technology.

The brains behind the machines

The work at PSI's large research facilities is challenging. Our researchers, engineers, and professionals are highly specialised experts. It is important for us to foster this expertise. So we want our employees to pass on their knowledge to the next generation, who will then put it to use in a variety of professional positions, not just at PSI. Around a quarter of our staff are therefore apprentices, doctoral students, or postdocs.

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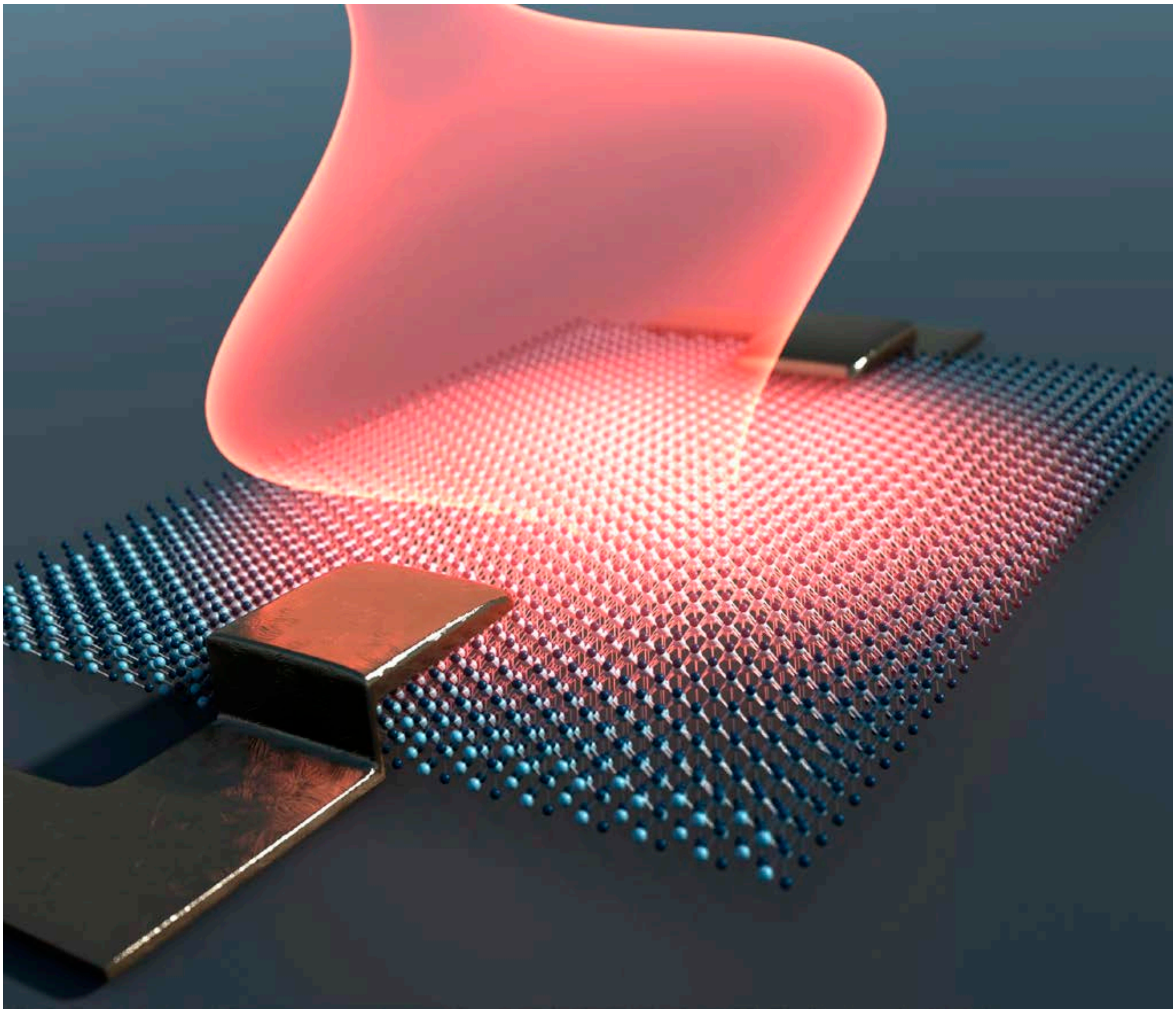
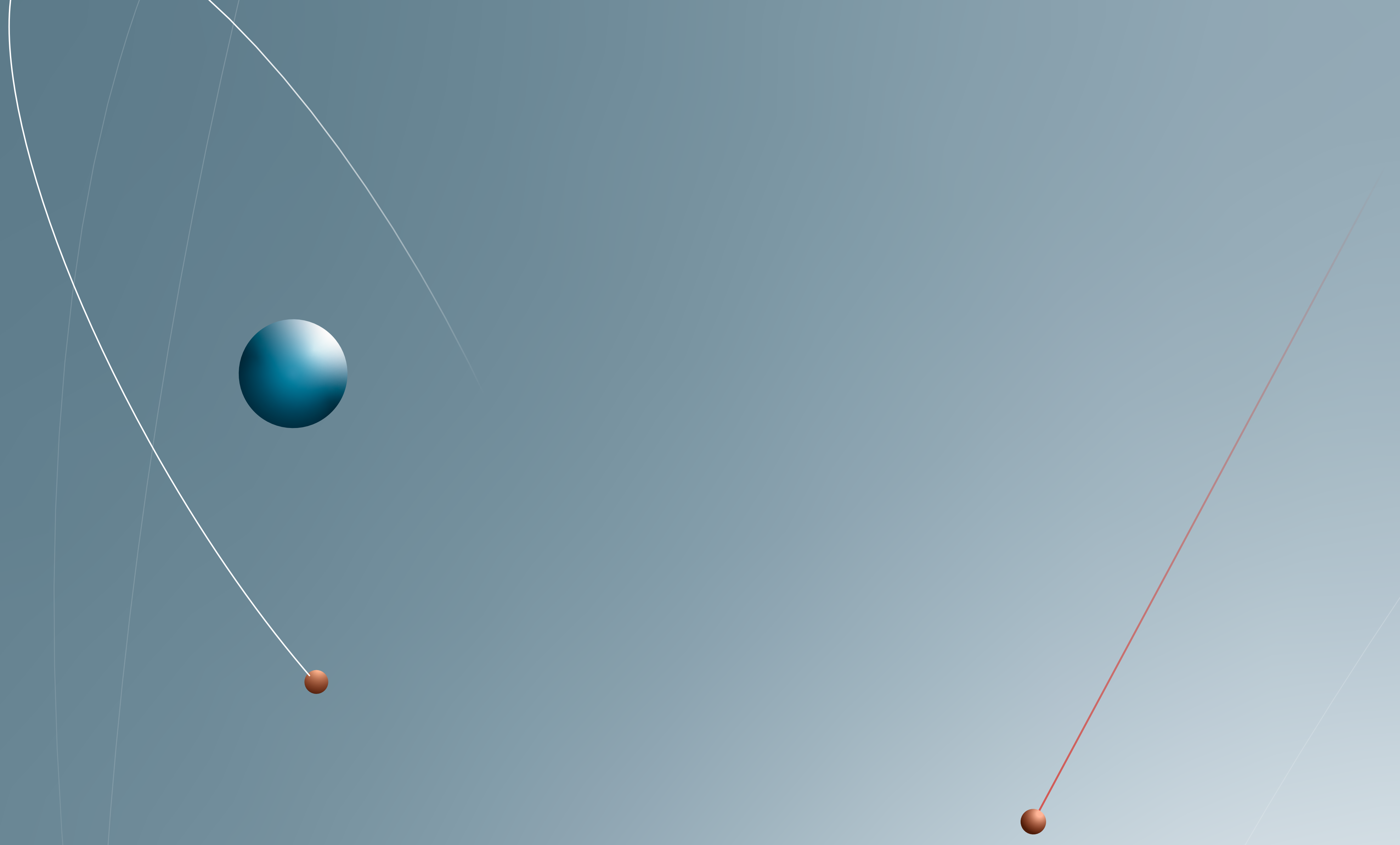


Coming up in the next issue

Since humans learned to master fire and use hand axes, they've worked ceaselessly to improve techniques and technologies. Often progress can be achieved only when it's possible to improve the necessary materials. This requires precise knowledge of their properties. That's why researchers at PSI are investigating how the building blocks of materials behave, how they can be combined in new ways, and what methods can be used to create completely new materials. This then opens the way, for example, to better energy storage solutions, novel materials for the construction of quantum computers, or more effective manufacturing processes.



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