ALLEGATO 1A

QUESITO 1

Cosa è un trasduttore piezoelettrico

ALLEGATO 1B

QUESITO 2

Schema generale di un sistema di acquisizioni dati

ALLEGATO 1C

QUESITO 3

Definizione di scarto quadratico medio

ALLEGATO 1D

QUESITO 4

Definizione di luce laser

ALLEGATO 2A

NEWS DIGEST

CNES/ill./D.Ducros

Free falling *An artist's impression of the MICROSCOPE satellite.*

Gravity under the microscope

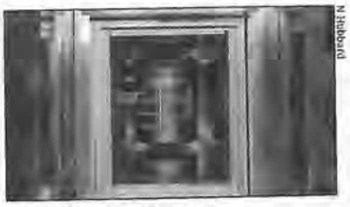
The MICROSCOPE collaboration has reported the most precise test of the weak equivalence principle (WEP), a cornerstone of general relativity which states that all bodies fall at the same rate in a gravitational field regardless of their composition or mass. Operated by the French space agency CNES, MICROSCOPE uses electrostatic forces to keep two cylinders made of platinum and titanium in equilibrium as they free-fall in Earth's orbit. After carefully monitoring the forces on the test masses for 2.5 years, the collaboration found no violation of the WEP, expressing the result in terms of the so-called Eötvös parameter: $[-1.52\pm2.3\,(\mathrm{stat})\pm1.5\,(\mathrm{syst})]\times10^{-15}$. The result, which places new constraints on possible violations of Lorentz invariance, bodes well for a next-generation mission aiming at sensitivities of 10^{-17}, says the team (*Phys. Rev. Lett.* **129** 121102).

Testing QED to the max

The world's most precise measurement of the electron magnetic moment has been claimed by Gerald Gabrielse and co-workers at Northwestern University. Via quantum-jump spectroscopy of one electron suspended in a Penning trap, the group determined g/2 in terms of the Bohr magneton, $-\mu/\mu_B$, to 1.001 159 652 180 59 (13), improving on their previous result by a factor of 2.2. This most precisely measured property of an elementary particle agrees with the Standard Model at the level of one part in 10^{13} – a test that will improve further when discrepant measurements of the fine-structure constant are resolved, reports the team (arXiv: 2209.13084).

Shining light on axions

Searching for solar axions in ^{76}Ge-enriched high-purity germanium detectors at Sanford Underground Laboratory in South Dakota, researchers working on the Majorana Demonstrator experiment have placed new constraints on the properties of these hypothetical particles. Due to the strong time–energy dependence of axion–photon conversion between the position of the solar axion's entry angle in the crystalline detector plane and the produced photon, solid-state detectors may enhance axion–photon conversion via the inverse Primakoff effect. Using data collected from January 2017 to November 2019, the collaboration placed a new limit at 95% confidence on the axion–photon coupling: $g_{a\gamma}<1.45\times10^{-9}\,\mathrm{GeV}^{-1}$. The result improves the limit from laboratory searches for axion masses between 1.2 to 100 eV (*Phys. Rev. Lett.* **129** 081803).



N Hubbard

Sensitive *The Majorana Demonstrator cryostat.*

FLASH therapy with ^{12}C ions

A team at the GSI Helmholtz Center in Darmstadt has reported the first *in vivo* application of "FLASH" radiotherapy using ^{12}C ions. The FLASH effect delivers an ultra-high dose of radiation for a very short time, destroying cancerous tissue but leaving healthy tissue undamaged. Marco Durante and co-workers divided mice that had a metastatic tumour implanted into a limb into three groups. Each group was treated either via FLASH, conventional, or "sham" radiotherapy at GSI's FAIR facility. FLASH irradiation was able to control the primary tumour in the limb and reduced the lung metastases significantly. Both effects were more pronounced than with conventional irradiation (*Radiother Oncol.* doi:10.1016/j.radonc.2022.05.003). In 2020, a collaboration between CERN and CHUV (Lausanne) was established to develop FLASH radiotherapy based on high-energy electrons (*CERN Courier* November/December 2020 p7).

BNL

Colourful *The STAR detector.*

QCD gets hotter

The STAR collaboration at Brookhaven's Relativistic Heavy Ion Collider has reported evidence of gluon saturation – a prediction of QCD whereby gluons at low transverse momenta recombine. If the rate of two gluons recombining into one balances out the rate of single gluons splitting, the gluon density reaches a steady state, or plateau. A smoking gun of such nonlinear gluon dynamics is a suppression in the yield of back-to-back decays of two neutral pions. By colliding protons with other protons as well as with aluminium and gold ions, the STAR team found the suppression to be proportional to the ion's mass number, as predicted by models of gluon recombination at low transverse momenta (*Phys. Rev. Lett.* **129** 092501).

CUPID-0 on neutrino's nature

Detecting neutrinoless double-beta decay ($0\nu\beta\beta$) would be a direct sign of lepton-number violation and thus of physics beyond the Standard Model, demonstrating that the neutrino is a Majorana particle. The first phase of CUPID (CUORE Upgrade with Particle Identification), a medium-scale $0\nu\beta\beta$ detector based on scintillating bolometric technology located in Gran Sasso, has produced its final results. Searching for $0\nu\beta\beta$ of ^{82}Se with a total exposure of 8.82 kg yr, the CUPID collaboration set a limit on the half-life of ^{82}Se to the ground state of ^{82}Kr of $>4.6\times10^{24}$ yr at 90% credible interval, corresponding to an effective Majorana neutrino mass $m_{\beta\beta}<(263\text{–}545)$ meV. According to the team, this is the most competitive result based on ^{82}Se (*Phys. Rev. Lett.* **129** 111801).

FCC-ee least disruptive

In terms of carbon footprint versus physics output, FCC-ee is the least disruptive of the proposed Higgs factories in terms of environmental impact, estimate Patrick Janot and Alain Blondel of the FCC Feasibility Study coordination group. While noting that their numbers "are not devoid of uncertainty", they found that the projected footprints per Higgs boson produced, evaluated using the 2021 carbon emission of available electricity, vary by a factor of 100 depending on the considered project (*Eur. Phys. J. Plus* **137** 1122).

Quantifying the thing called swing

Delayed beats can cause a breakdown in a piece of music – except in jazz, and especially in Swing jazz, which emerged at the end of the 1920s. Yet, the essence of why tunes "swing" has remained mysterious. In a new study, physicists and psychologists from the University of Göttingen analysed 456 jazz piano solos with downbeat–offbeat pairs from the Weimar Jazz Database, concluding that an occasional delay of as little as 30 ms is a key component of swing. The findings were supported by an experiment in which professional jazz musicians were asked if four prepared tunes, each with different downbeat–offbeat pairs, swing (*Commun. Phys.* **5** 237).

ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

ATLAS

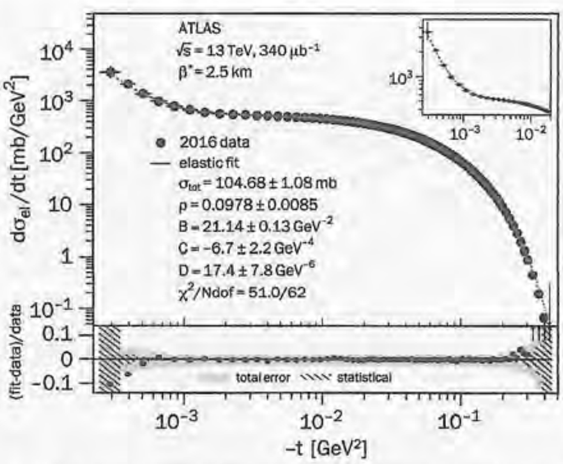
Probing QCD beyond LHC energies

The study of elastic hadron scattering is a cornerstone in understanding the non-perturbative properties of strong interactions. A key role is played by experiments at the LHC, where it is possible to precisely measure proton–proton (pp) interactions at a very high centre-of-mass energy. The goal is to detect the process pp → pp, in which the interacting protons remain intact and are scattered at angles of a few microradians with respect to the beamline. The importance of such measurements follows from their relation to the total hadronic pp cross section via the optical theorem, and to properties of proton interactions at asymptotically high energies via dispersion relations.

In ATLAS, elastic scattering is studied using a dedicated experimental setup – the ALFA detectors, which allow measurements of scattered-proton trajectories inside the beam pipe, just a few millimetres from the LHC beam. They are installed inside so-called Roman pots located at distances of 237 and 245 m on either side of the ATLAS interaction point.

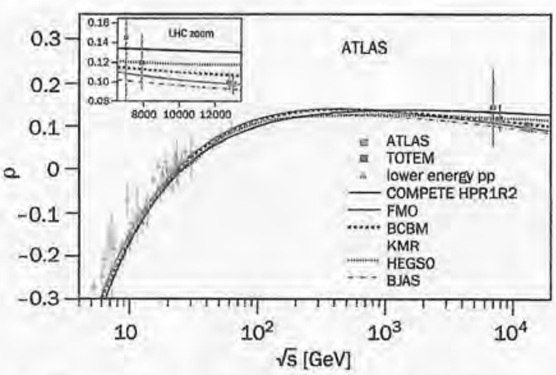
Recently, ATLAS reported a measurement of el[illegible]tic scattering at a centre-[illegible]rgy of 13 TeV. The data were co[illegible]h a special setting of the LHC magnets characterised by a high β* of 2500 m, which results in a large beam-spot size and a very small beam divergence. The latter allows precise measurements of small scattering angles. With these optics, the ALFA system detected events characterised by very small values of the Mandelstam t variable, which is proportional to the scattering angle squared. Measurements of small |t| values give access to the Coulomb–nuclear interference (CNI) kinematic region, where the contribution from electromagnetic and strong interactions are of similar magnitude.

The ALFA detectors use scintillating-fibre technology to measure the position of the passing proton. The t value for each event is reconstructed from the measured positions using knowledge of the magnetic fields of the LHC magnets between the interaction point and the detectors. The selection of candidate events is based on the strong correlations between the elastically scattered protons, resulting



Source: arXiv:2207.12246

Fig. 1. *The measured differential elastic proton–proton cross section as a function of the Mandelstam t variable together with a fit function used to extract the physics parameters.*



Source: arXiv:2207.12246

Fig. 2. *The centre-of-mass energy evolution of the ρ parameter together with predictions of various theoretical models.*

from energy and momentum conservation. The analysis is heavily based on data-driven techniques, which are used for the alignment of the detectors, background estimation, evaluation of reconstruction efficiency and optics tuning.

Figure 1 presents the measured differential elastic cross section as a function of t. The shape of the distribution is sensitive to important physics parameters, such as the total cross section (σ_{tot}) and the ρ parameter, defined as the ratio of real to imaginary parts of the forward scattering amplitude. The smallest |t| values, and thus the smallest scattering angles, are dominated by the electromagnetic interaction between the protons. The CNI effects are strongest for |t| around 10^{-3} GeV^2 and provide the sensitivity to the ρ parameter. For larger |t| values, the strong interaction dominates, and the spectrum depends on the value of σ_{tot}. The physics parameters are extracted from a fit to the t distribution.

The ρ parameter is related, through dispersion relations, to the energy dependence of σ_{tot}, with a certain sensitivity also to energies above those at the LHC. In addition, ρ is sensitive to possible differences between pp and $p\bar{p}$ scattering amplitudes at asymptotic energies. ATLAS measured ρ = 0.098 ± 0.011, in agreement with a previous TOTEM measurement. The result is in conflict with pre-LHC theoretical expectations (see the COMPETE line in figure 2), which assumed that no pp/$p\bar{p}$ difference is present asymptotically and that σ_{tot} increases proportionally to the squared logarithm of the centre-of-mass energy, similarly to the evolution observed at accessible energies back then. This suggests that one of the above assumptions is incorrect: either the increase of σ_{tot} slows down above LHC energies, or protons and antiprotons interact differently at asymptotic energies. The second statement is often associated with the so-called odderon exchange. Both possibilities affect our understanding of the high-energy behaviour of strong interactions.

ATLAS also measured the total pp hadronic cross section σ_{tot} = (104.7 ± 1.1) mb. This is the most precise measurement to date at this energy, due to a dedicated luminosity measurement that contributed less than 1 mb to the total systematic uncertainty. However, the long-standing tension between the ATLAS and TOTEM σ_{tot} measurements, with the latter being about 5% higher than ATLAS, persists.

ATLAS has collected more elastic scattering data in LHC Run 2, which are currently being analysed. New data taking is planned during Run 3, where a special run is foreseen at a centre-of-mass energy of 13.6 TeV.

Further reading

ATLAS Collab. 2022 arXiv:2207.12246.

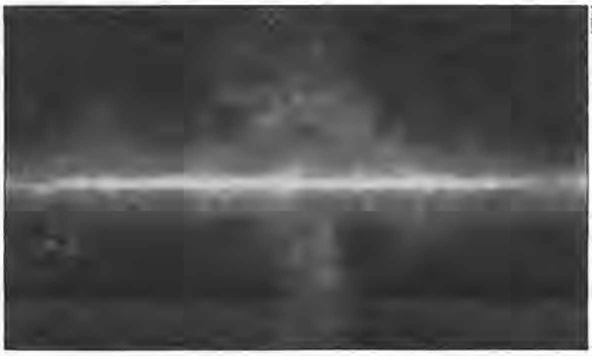
ASTROWATCH

Probing the Milky Way's violent history

Active galactic nuclei (AGN) are one of the most studied astrophysical objects. Known to be the brightest persistent sources of photons in the radio to gamma-ray spectrum, they are also thought to be responsible for high-energy cosmic rays and neutrinos. As such, they play an important role in the universe and its evolution.

AGNs are galaxies in which the supermassive black hole at their centre is accreting matter, thereby producing violent jets responsible for the observed emissions. While our galaxy has a supermassive black hole at its centre, it is currently not accreting matter and therefore the nucleus of the Milky Way is not active. Strong hints of past activity were, however, discovered using the Fermi-LAT satellite in 2010. In particular, the data showed two giant gamma-ray emitting bubbles – now known as the Fermi bubbles – extending from the galactic centre and covering almost-half of the sky (see image). The exact origin of the giant plasma lobes remains to be understood. However, their position and bipolar nature point towards an origin in the Milky Way's centre several million years ago, likely during a period of high activity in the galactic nucleus.

A new study led by Trisha Ashley from the Space Telescope Science Institute, Baltimore, brings a fresh perspective on the origin of these structures. Her team focused on the chemical composition of gas clouds inside the bubbles using UV absorption data collected by the Hubble Space Telescope and Green Bank Telescope. Based on their location and movement, these high-velocity clouds had been assumed to originate in the disk of the Milky Way before being swept up as the bubbles were emitted from the galactic centre. However, measurements of the clouds' elemental makeup cast doubt on this assumption.



NASA

Mysterious *Discovered in 2010, the "Fermi bubbles" (magenta) are giant plumes of gamma rays emerging above and below the galactic plane.*

UV surprise

Gas clouds from the galactic disk should have a similar chemical composition (referred to as metallicity by astronomers) to those that once collapsed into stars like the Sun. In the galactic disk, the abundance of elements heavier than hydrogen (high metallicity) is expected to be higher thanks to several generations of stars responsible for the production of such elements, whereas in the galactic halo the metallicity is expected to be lower due to a lack of stellar evolution. To measure the chemical composition of the gas clouds, Ashley and her team looked at the UV spectra from sources behind them to see the induced absorption lines. To their surprise, they found not only clouds with high metallicity but also those with a lower metallicity, matching that of galactic halo gas, thereby implying a different origin for these clouds. Suggestions that the second class of clouds is a result of heavy clouds accumulating low-metallicity gases are unlikely to hold, as the time it would take to absorb these gases is significantly longer than the age of the Fermi bubbles. Instead, it appears that while the bubbles did drag along gas clouds from the galactic plane, they also swept up existing halo gas clouds as they expanded outwards.

These results imply that events such as those which produced the Fermi bubbles play an important role in gas accumulation in a galactic plane. They remove gas from the galactic disk, while in parallel, push back gas flowing into the galactic disk from the halo. As less gas reaches the disk, star formation gets suppressed, and as such, these events play an important role in galaxy evolution. Since studying small-scale details such as gas clouds in other galaxies is impossible, these results provide a unique insight into our own galaxy as well as into galaxy evolution in general.

Further reading

T Ashley *et al.* 2022 *Nat. Astron.* **6** 895.

EDUCATION AND OUTREACH

Farewell Microcosm, hello Science Gateway

Having engaged innumerable visitors in the world of particle physics for the past 32 years, the CERN Microcosm closed its doors for the last time on 18 September in preparation for CERN's new flagship Science Gateway project, opening in 2023. The well-loved exhibition space opened to the public in 1990 to help CERN share its research openly, offering a glimpse behind the scenes to both tourists and schools alike.

Over the years, the exhibitions have evolved considerably. The first version of Microcosm included an exhibition by the European Space Agency, highlighting the strong ties between CERN and other European research organisations, which continue today through the EIROforum network. In 1997 CERN Director-General Chris Llewellyn Smith inaugurated a revamped exhibition with content in four languages and stories of new projects such as the LHC. Two years later, a new exhibition was added to Microcosm's portfolio, telling the story of research on the weak force, with large pieces of the Antiproton Accumulator and the UA1 and UA2 detectors. The 2000s brought hands-on experimentation for the first time and a demo area for science shows.

CERN-PHOTO-201603-050-2

Bringing physics to life *The most recent Microcosm exhibitions featured realistic audiovisual content of scientists and engineers.*

In 2014 S'Cool LAB arrived, home to the expanding programme of experimentation for high-school students and teachers. And in 2015 the latest version of Microcosm opened, with new exhibitions offering a behind-the-scenes tour of the lab, together with realistic audiovisual content of scientists and engineers.

In recent years, Microcosm has also made great strides towards improving accessibility, with wheelchair-accessible design, signing and subtitling for the deaf and hard of hearing, and tactile content for the visually impaired – an effort that will be continued and strengthened at Science Gateway. "Microcosm has been strongly supported by many at CERN over the years," says Emma Sanders, head of exhibitions at CERN. "I suspect I won't be the only one to feel a little emotional on its closure, but we all look forward to the next step, with the opening of Science Gateway next June."

QUANTUM INFORMATION

Nobel recognition for quantum pioneers

Foundational *From left: Nobel winners Alain Aspect, John Clauser and Anton Zeilinger.*

Announced on 4 October, the 2022 Nobel Prize in Physics has been awarded to Alain Aspect, John Clauser and Anton Zeilinger for groundbreaking experiments with entangled photons that open a path to advanced quantum technologies. Working independently in the 1970s and 1980s, their work established the violation of Bell inequalities – as formulated by the late CERN theorist John Bell – and pioneered the field of quantum information science.

First elucidated by Schrödinger in 1935, entanglement sparked a long debate about the physical interpretation of quantum mechanics. Was it a complete theory, or was the paradoxical correlation between entangled particles due to hidden variables that dictate in which state an experiment will find them? In 1964 John Bell proposed a theorem, known as Bell's inequalities, that allowed this question to be put to the test. It states that if hidden variables are in play, the correlation between the results of a large number of measurements will never exceed a certain value; conversely, if quantum mechanics is complete, this value can be exceeded, as measured experimentally.

John Clauser (J F Clauser & Associates, US) was the first to investigate Bell's theorem experimentally, obtaining measurements that clearly violated a Bell inequality and thus supported quantum mechanics. Alain Aspect (Université Paris-Saclay and École Polytechnique, France) put the findings on even more solid ground by devising ways to perform measurements of entangled pairs of photons after they had left their source, thus ruling out the effects of the setting in which they were emitted. Using refined tools and a long series of experiments, Anton Zeilinger (University of Vienna, Austria) used entangled states to demonstrate, among other things, quantum teleportation.

These delicate, pioneering experiments not only confirmed quantum theory, but established the basis for a new field of science and technology that has applications in computing, communication, sensing and simulation. In 2020 CERN joined this rapidly growing global endeavour with the launch of the CERN Quantum Technology Initiative.

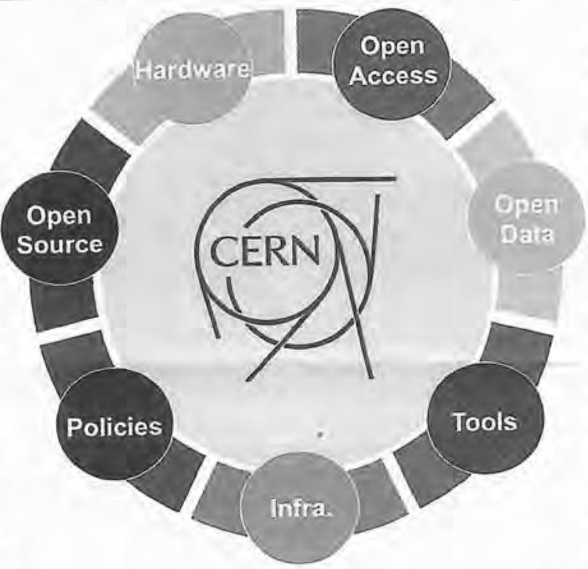
Foundational work in quantum-information science was also the subject of the 2023 Breakthrough Prize in Fundamental Physics, announced in September, for which Charles H Bennett (IBM), Gilles Brassard (Montréal), David Deutsch (Oxford) and Peter Shor (MIT) will receive $3 million each (see p52).

OPEN SCIENCE

CERN opens new era in knowledge sharing

In September, CERN approved a new policy for open science, with immediate effect. Developed by the Open Science Strategy Working Group (OSWG), which includes members from CERN departments and experiments, the policy aims to make all CERN research fully accessible, reproducible, inclusive, democratic and transparent for both researchers and wider society.

Open science has always been one of CERN's key values, dating back to the signing of the CERN Convention at UNESCO in 1952. The new policy follows the 2020 update of the European Strategy for Particle Physics, which highlighted the importance of open science, and UNESCO's Recommendation on Open Science, published in 2021. It encompasses the existing policies for open access and open data, which make all



research papers and experimental data publicly available. It also brings together other existing elements of open science – open-source software and hardware, research integrity, open infrastructure and research assessment (which make research reliable and reproducible) and training, outreach and citizen science, which aim to educate and create dialogue with the next generation of researchers and the public.

"The publication of the Open Science Policy gives a solid framework in which the popular suite of open-source tools and services provided by CERN, including Zenodo, Invenio and REANA, can continue to grow and support the adoption of open-science practices, not only within physics but also across the globe's research communities," said Enrica Porcari, head of CERN's IT department.

The OSWG will continue to assess how open science evolves at CERN, developing the policy in accordance with new best practices. Alongside this, a new open-science report will be published each year, showing CERN's continued commitment to the initiative.

- https://openscience.cern.