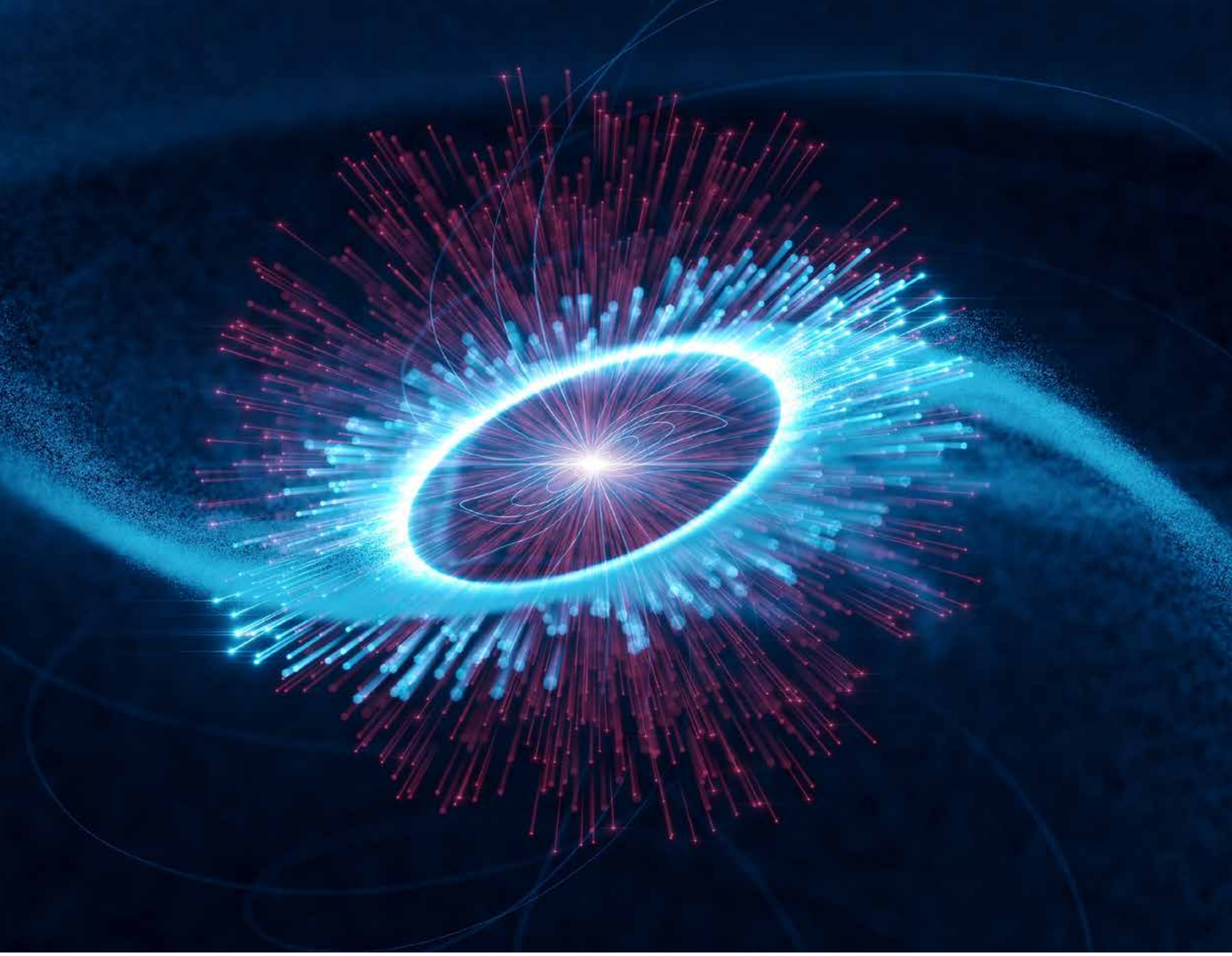


ASTROPARTICLE PHYSICS 2023.

Highlights and Annual Report

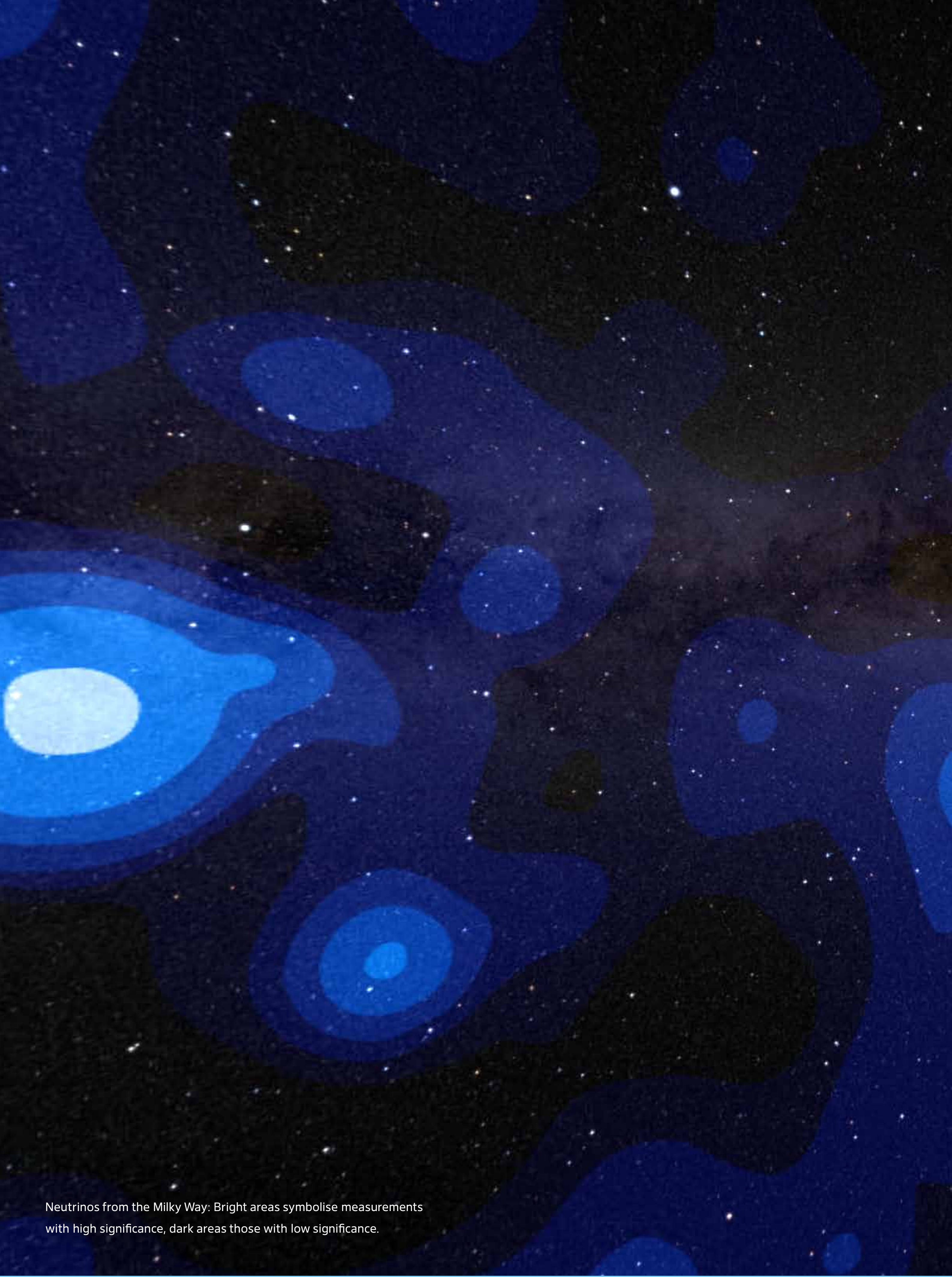
Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

Cover

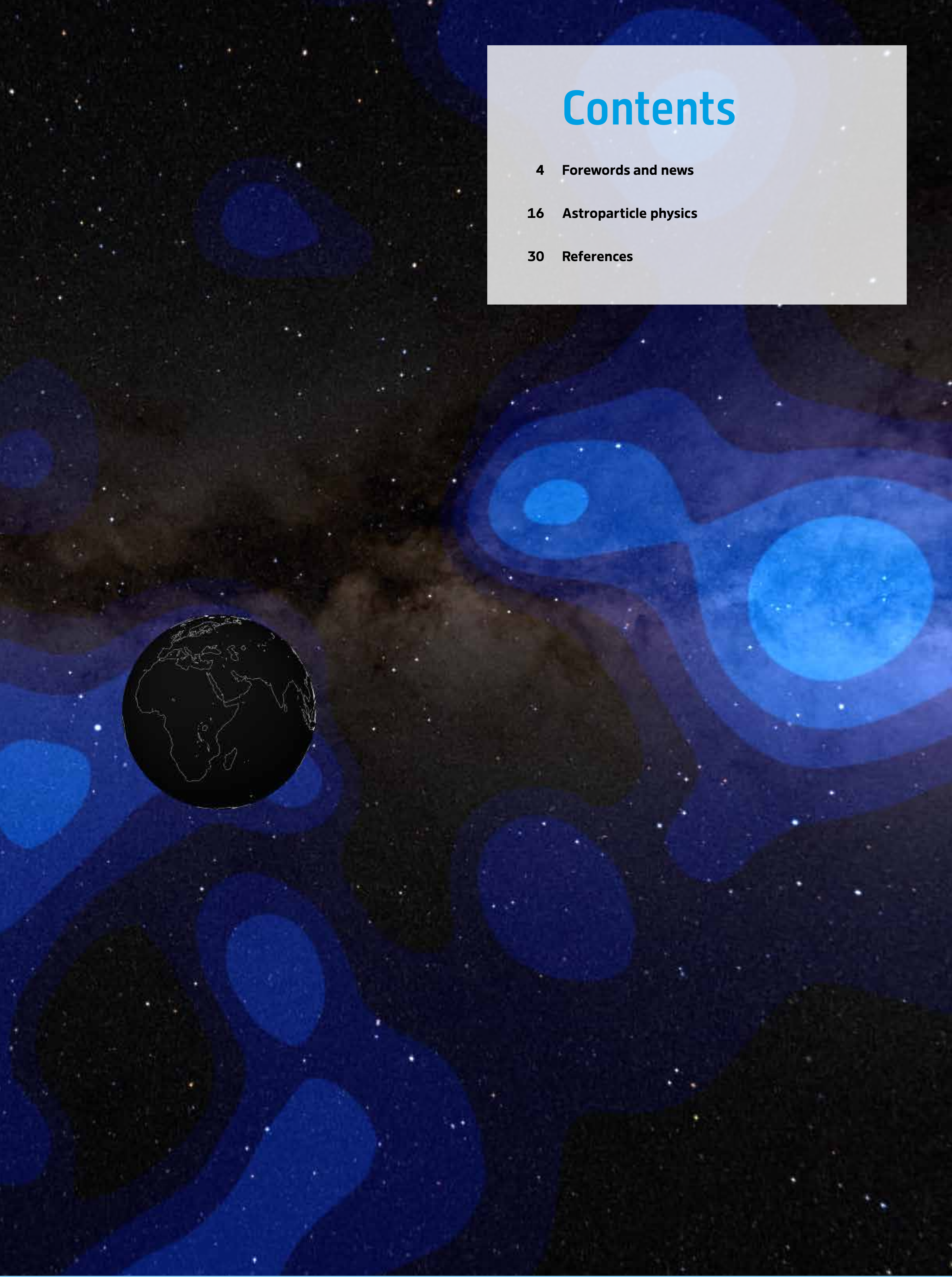
Researchers assume that infrared photons from the poles of the Vela pulsar are boosted to gamma-ray energies (blue) by fast electrons.

ASTROPARTICLE PHYSICS 2023.

Highlights and Annual Report



Neutrinos from the Milky Way: Bright areas symbolise measurements with high significance, dark areas those with low significance.



Contents

The year 2023 at DESY

Chairman's foreword

Dear Colleagues and Friends of DESY,

The world is facing unprecedented challenges. The consequences of climate change are becoming increasingly evident in devastating extreme weather events. Even as the aftershocks of the COVID-19 pandemic continue, we are still exposed to potential new viral and bacterial pathogens whose effects we do not know. Concurrently, the global community is shaken by geopolitical upheavals: Putin's horrifying war in Ukraine and the brutal terrorist attacks on Israel, just to name a few. Now more than ever, we must advocate for a sustainable and peaceful future so that we do not leave a ruined world for future generations.

What role can a research centre like DESY play in shaping a liveable future in Germany, Europe and the world? How can DESY contribute to limiting climate change and to preventing future pandemics and other health issues? And how do we navigate international collaborations with partners from nations that challenge democratic values, such as China?

Preliminary answers to these questions can be found in our draft of the DESY Strategy 2030 Loop. Under the guiding principle "The Decoding of Matter", DESY remains deeply rooted in fundamental research. Our commitment as a national centre to the international particle physics organisation CERN remains unchanged, and we continue to expand astroparticle physics. A significant move in this direction is the establishment of the German Center for Astrophysics (DZA) in the Lausitz region – a political decision to which Christian Stegmann, Director in charge of Astroparticle Physics at DESY, has made significant contributions. By 2024, decisions should be made regarding DESY's position within the DZA.

In recent months, we have vigorously advocated for the timely realisation of DESY's flagship project, PETRA IV. The conversion of our existing synchrotron radiation source PETRA III into a state-of-the-art fourth-generation X-ray light source is essential to remain competitive worldwide.

Figure 1
DESY researcher Johannes Hagemann (left) shows German Health Minister Karl Lauterbach (right) the experiments at the PETRA III beamline P06 together with Helmut Dosch (second from left), Hamburg Science Senator Katharina Fegebank (middle) and Gesa Miehe-Nordmeyer from the Federal Chancellery (second from right).

Figure 2
Visualisation of the DESY visitor centre DESYUM, close to the main entrance on the DESY campus in Hamburg

In particular, the USA and Asia are already heavily investing in similar research infrastructures. All our endeavours regarding PETRA IV have received substantial local political backing from the Hamburg Parliament, which committed to funding 10% of the project's investment costs. This strong support continues at the national level: During the Federal Budget Committee session on 16 November 2023, a decisive step was taken with the approval of 40 million euros in seed funding for the project – highlighting the pivotal relevance of PETRA IV for future science.

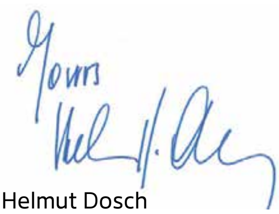
Over the past months, we have seen remarkable support from the high-tech and deep-tech industries. Our industrial dialogue partners recognise that they stand at the brink of a profound transformation: Climate change solutions demand a shift towards sustainable materials and processes, while precision data emerges as the new currency in international competition. Those with the best databases will lead AI-driven developments, be it in custom materials or pharmaceuticals. Fourth-generation synchrotron radiation facilities are globally recognised as vital for generating this invaluable pool of data.

The coming decade will be pivotal for our research centre. For DESY, it is crucial to ensure the swift implementation of PETRA IV and further advance photon science, uphold our leadership in plasma-based particle acceleration developments, expand new methods in astroparticle physics and make a significant national contribution to the High-Luminosity Large Hadron Collider (HL-LHC) at CERN. Concurrently, we must ambitiously drive our vision of creating a dynamic research innovation ecosystem with DESY at the core of the Science City Hamburg Bahrenfeld, incorporating innovative and sustainable digital structures and processes.

Realising this master plan is in itself a monumental challenge. The current financial situation, with volatile energy and gas prices among other effects leading to rising inflation, poses significant difficulties for the DESY management. We face a new reality at DESY: the need to craft a globally competitive research programme with diminishing resources, which is achievable only with stringent prioritisation. The dramatic rise in the construction cost index in recent years has jeopardised several of our planned construction projects. However, we were able to successfully launch the civil engineering work for our DESYUM visitor centre in Hamburg as the first major construction initiative. Construction is progressing swiftly, giving us hope that we will meet all set milestones on time. Up next is the new accelerator centre CAST, which will also house the accelerator control room and the DESY Innovation Factory, a centre for start-ups. Ideally, we would like to implement these projects before the intensive construction phase of PETRA IV.

DESY is held in high international regard in fundamental research. It is imperative to emphasise that our success would be inconceivable without talented researchers and engineers who consistently pioneer the development of new technologies. My special thanks therefore go to them and all the DESY staff, our national and international users as well as our partners for their dedicated work. This is also reflected in the numerous awards and grants they have earned, including several prestigious European Research Council (ERC) grants.

The crucial message is: We must persistently strive to cultivate an attractive and innovative environment for the world's brightest minds, or risk falling behind in the international competition – and this is not just about DESY. In challenging times, the ability to provide answers to difficult questions is needed more than ever, and this is precisely where the strength of fundamental science lies. The scientific results in this annual report are good examples of what we can achieve when we work together for a better future!



Helmut Dosch
Chairman of the DESY Board of Directors

Astroparticle physics at DESY

Director’s foreword

Dear friends of DESY,

We live in challenging times. Even as the COVID-19 pandemic receded, 2023 saw an increase in conflicts that has numerous implications for both the political situation and the scientific landscape in Europe and beyond. As a research centre whose success is founded on international collaboration, DESY firmly upholds the democratic values on which our peaceful coexistence and cooperation in Europe and with our partners around the world is based.

As I wrote on the occasion of the second Diversity Day at DESY in May 2023: “DESY is diverse, the people who work here come from many nations, have different origins, bring different identities and perspectives. Each and every one enriches us. This diversity is sometimes exhausting, but it makes us strong. Especially in difficult times, it is important to promote equal opportunities and solidarity and to set an example for diversity.” It is this spirit of open-mindedness, tolerance and mutual respect that makes DESY such a great place to work – and that ensures its success as one of the world’s top centres for research into the structure of matter and the universe.

The progress of our research projects testifies to the success of this approach, with all the endeavours of the DESY Astroparticle Physics Division reaching decisive milestones in 2023. In particular, preparations are in full swing for the construction of the telescopes and infrastructure for the upcoming Cherenkov Telescope Array Observatory (CTAO) – a unique, world-class observatory for gamma-ray astronomy with over 60 telescopes at two sites in Chile and on the Canary Island of La Palma. Construction work on the observatory’s Science Data Management Centre (SDMC) on our Zeuthen campus proceeded as planned, with completion expected in autumn 2024. In addition, DESY is in charge of providing a total of 42 cameras for the Small-Sized Telescopes (SSTs), which are approaching their final design. In 2023, electronic components for the cameras were manufactured and used to build a development and test model of the camera. Furthermore, DESY is responsible for the design and production of the Medium-Sized Telescopes (MSTs). The DESY design was approved by CTAO at the end of 2023 after a thorough review. As the next step, two prototype MSTs will be manufactured at DESY and prepared for installation at both observatory sites.

The development of the camera for the ULTRASAT space telescope, a satellite mission led by the Weizmann Institute of Science (WIS) and the Israel Space Agency (ISA), made very good progress. Major steps were taken towards the first version of the camera, and the production phase was initiated. First tests of the readout chain of the sensors – which will take images in the near-ultraviolet with 90 million pixels every five minutes to search for time-varying cosmic sources – were successful.

In neutrino astronomy, work continued to focus on the IceCube

Members of the International Helmholtz–Weizmann Research School for Multimessenger Astronomy at their annual meeting in June 2023

neutrino telescope at the South Pole and on the Radio Neutrino Observatory Greenland (RNO-G). IceCube is currently being upgraded in collaboration with US partners, KIT in Karlsruhe and several university groups. New optical modules with more sensitive light detection, called multi-photomultiplier tube digital optical modules (mDOMs), have been developed at DESY and elsewhere for this purpose. Equipped with 24 photomultipliers each, they have about twice the light-sensitive area of their predecessors in IceCube and allow intrinsic directional determination of the measured light. Their development was successfully completed in 2023 with a production readiness review, and the integration and testing of 225 mDOMs at DESY is now well under way. By the end of 2023, more than 100 mDOMs had been produced and successfully tested. The detection of neutrinos with petaelectronvolt (PeV) energies using radio waves is an important addition to IceCube, which is being studied with the RNO-G pilot array in Greenland. Here, the year 2023 was used to improve the drilling technology and the autonomous energy supply and to calibrate the stations already installed, building on the experience gained with the first seven stations.

IceCube also delivered one of the scientific highlights of the year, which we are pleased to present to you in this report. Using a novel analysis technique developed mainly at DESY and RWTH Aachen, the IceCube researchers performed the most accurate measurement of the cosmic neutrino spectrum to date. For the first time, evidence was found for a break in the spectral shape, providing important clues about the nature of the environments in which the neutrinos are produced. To further boost analysis capabilities, DESY released the Astrophysical Multi-Messenger Modeling (AM3) software, which can be used to simulate multimessenger emission – including neutrinos – from active galactic nuclei, blazars and gamma-ray bursts. Further scientific highlights included the detection by the H.E.S.S. telescope of very-high-energy gamma-ray emission from the outer jets of a microquasar, insights from observations by the VERITAS telescope that reveal the potential origin of a galactic "PeVatron" candidate – a cosmic-ray factory that accelerates particles to PeV energies – and a novel analysis of the production mechanisms of particle cascades generated by gamma-rays from distant blazars.

These successes, which have been published in high-ranking scientific journals, attest to the excellent research being carried out in the DESY Astroparticle Physics Division despite the current tight staffing situation. So do the prizes and awards conferred to members of the division, including two distinctions for outstanding PhD theses – for Annika Rudolph from the German Astronomical Society and for Robert Stein from the German Physical Society – as well as a Starting Grant from the European Research Council (ERC) for Anna Nelles to fund the construction of the RNO-G network of radio antennas on Greenland.

The Helmholtz–Weizmann International Research School for Multimessenger Astronomy, in which DESY is strongly involved, continues to deliver excellent results, with the students of the second cohort having finished the School and new students recruited for a doctorate for the sixth time. To further the public understanding of science and inspire young people in particular to take an interest in science, the division continued to actively promote young talent and outreach activities, for example through its School Lab, the first AstroCamp, featuring the launch of a research balloon, the first DESY–Ukraine Winter School, the traditional summer student programme and several other events organised on the occasion of the "Science Year 2023 – Our Universe" declared by the German Federal Ministry of Education and Research (BMBF).

I would like to thank all our staff and our partners in Germany and around the world for contributing to our joint successes in the past year, and I am looking forward to continuing our cooperation – based on our common values of open-mindedness, tolerance and respect – in the years to come.

Christian Stegmann
Director in charge of Astroparticle Physics

News and events

Highlights in 2023

January

DESY honoured as bicycle-friendly employer

DESY has once again been recognised as a bicycle-friendly employer by the German Cyclists' Club (ADFC). The Hamburg site received the gold certificate for the second time – as one of only two employers in the city. The Zeuthen site was again certified with bronze.

DESY–Ukraine Winter School creates opportunities

Participants of the first DESY–Ukraine Winter School at DESY in Zeuthen

The first DESY–Ukraine Winter School was held from 31 January to 10 March. A total of 22 students from Ukrainian universities worked on DESY research projects on the Hamburg and Zeuthen campuses for six weeks. The projects enabled the students to interact with scientists in research areas that would otherwise have been out of reach given the current geopolitical situation. The programme included projects from all areas of research at DESY, complemented by a lecture series on the relevant physics basics.

February

Paul Söding celebrates 90th birthday

He is a DESY veteran in the best sense of the word: Particle physicist, former DESY Research Director and recipient of the Federal Cross of Merit Paul Söding turned 90 in February. He was closely associated with DESY throughout his scientific life and shaped the research centre for decades. In 1992, Söding took over the management of the Zeuthen site, where, until his retirement in 1998, he ensured that the two DESY locations were brought together on an equal footing and initiated a reorientation of the scientific profile of the new site.

Astroparticle Physics retreat

On 21 and 22 February, the scientific groups of the Astroparticle Physics Division gathered in Potsdam for their first major face-to-face meeting after the COVID-19 pandemic. Lively exchanges took place on cross-group topics, ranging from the astrophysics of transient events and serendipitous discoveries to instrument development and the organisation of information flow in the Astroparticle Physics Division.

Anna Nelles talking at the retreat of the Astroparticle Physics Division

Testing of mDOMs for the upgrade of IceCube

mDOM production at DESY in Zeuthen begins

The large-scale production and testing of new multi-photomultiplier tube (PMT) digital optical modules (mDOMs) for the upgrade of the IceCube neutrino observatory at the South Pole has officially begun. In February, DESY completed the assembly of 20 of a total of 225 mDOMs at a hall in Schönefeld. The modules were then shipped to the DESY campus in Zeuthen for testing and characterisation. The next stop for the modules that pass all the tests and fulfil the necessary requirements will be at their final location at the South Pole, 2.7 km underground in the Antarctic ice.

March

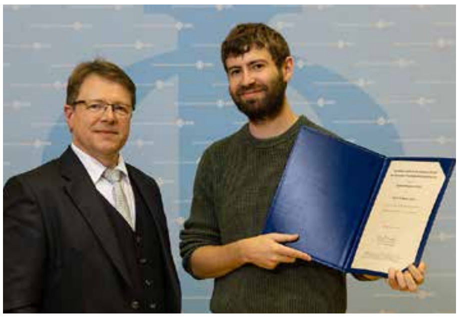
mDOM Production Readiness Review

On 9 and 10 March, the mDOM Production Readiness Review of the new modules for the IceCube neutrino observatory took place at DESY in Zeuthen. The whole mDOM team at DESY – from the management to the technicians – had done an exceptional job and duly impressed the review panel.

IceCube Impact Award for Cristina Lagunas Gualda

Cristina Lagunas Gualda, a PhD student in the DESY Neutrino Astronomy group, received the IceCube Impact Award for her "leadership in investigations into the characterisation of track reconstruction, including angular errors, for real-time alerts". The IceCube Impact Awards, established in 2018, recognise broad and significant contributions to the IceCube neutrino observatory that would not normally be acknowledged through its publications.

Cristina Lagunas Gualda



Robert Stein (right) with DPG Vice President Lutz Schröter

Robert Stein receives DPG Dissertation Prize

The section "Matter and Cosmos" of the German Physical Society (DPG) awarded DESY PhD student Robert Stein the 2023 DPG Dissertation Prize. He was honoured for his work "Black Holes, Shredded Stars and Cosmic Neutrinos", in which he investigated the connections between tidal disruption events, a type of cosmic tidal catastrophe, and high-energy neutrinos, using data from IceCube at the South Pole and from the Zwicky Transient Facility (ZTF), an optical observatory in the USA. The prize was presented to Robert Stein at the DPG conference in Dresden at the end of March.

April

SEVAN detector installed on Zugspitze Mountain

In mid-April, the Zeuthen SEVAN detector was installed at Germany's highest research station on the Zugspitze Mountain. The device is part of the Space Environment Viewing and Analysis Network (SEVAN) of detectors at mountain stations in Armenia, Bulgaria, the Czech Republic and Slovakia, developed by the A. Alikhanyan National Lab in Yerevan, Armenia, to measure different cosmic particle species simultaneously. Its data will be made available to the DESY data analysis system Cosmic@Web for young people and students.

The Zeuthen SEVAN detector installed on the Zugspitze Mountain

Zukunftstag at DESY

On 27 April, 29 girls and boys attended the "Zukunftstag" (Future Day) at the campus in Zeuthen. After a welcome and an overview of DESY and its research, the young guests were supervised in the groups so they could familiarise themselves with specific job profiles – from the workshops to the scientific groups and the administrative area. In the feedback session at the end of the day, the programme was described as very diverse and varied.

May

DESY at the Potsdam Science Day

DESY represented the Dahme-Spreewald district on 6 May at the Potsdam Science Day together with TH Wildau and Dahme Innovation. The three institutions provided information about their research and the opportunities they offer in the fields of education and study. Visitors young and old were able to discover the fascinating world of physics and everyday phenomena with vacuum experiments from the DESY School Lab.

The DESY booth at the Potsdam Science Day

Topping-out ceremony for the Science Data Management Centre of the CTAO gamma-ray observatory

Topping-out ceremony for CTAO data centre

On 23 May, the topping-out ceremony for the Science Data Management Centre (SDMC) of the upcoming Cherenkov Telescope Array Observatory (CTAO) was celebrated together with the companies and craftspeople involved in the construction. The completion of the structural works for the SDMC marked an important milestone in the construction measures on the Zeuthen campus.

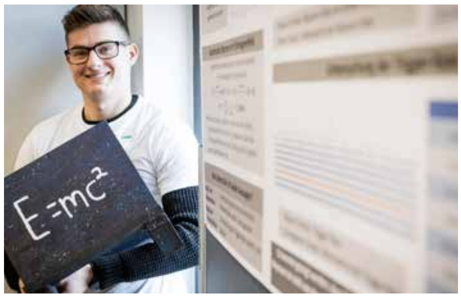
Diversity Day

"DESY is diverse, the people who work here come from many nations, have different origins, bring different identities and perspectives. Each and every one enriches us. This diversity is sometimes exhausting, but it makes us strong. Especially in difficult times, it is important to promote equal opportunities and solidarity and to set an example for diversity," said Christian Stegmann's invitation to the second Diversity Day at DESY in Zeuthen. The nationwide day of action was celebrated on 23 May.

Celebrating Diversity Day at DESY

"Jugend forscht" projects in the CosmicLab

Under the supervision of the DESY CosmicLab in Zeuthen, four young people submitted projects to the "Jugend forscht" science competition: One student won the Hessen West regional competition and came third in the state competition. Another student took part in the Brandenburg East regional competition, and two students achieved second place in the Berlin state competition.



Marcel Göttel won the "Jugend forscht" Hessen West regional competition and came third in the state competition.

June

Multimessenger Astronomy Research School in Israel

At the beginning of June, doctoral students and supervisors of the International Helmholtz–Weizmann Research School for Multimessenger Astronomy travelled to Israel to meet fellow scientists at the Weizmann Institute of Science. The programme of the yearly meeting included presentations of the students' current research, talks by invited speakers and an excursion to Jerusalem.

Participants of the Multimessenger Astronomy Research School in Israel

Long Night of the Sciences

On 17 June, the Humboldt University of Berlin and DESY presented their research to the public with exhibits and talks on particle and astroparticle physics at the Long Night of the Sciences in Berlin-Adlershof. A special highlight was the mobile exhibition "Big Bang on the road – Time travel from the present to the Big Bang". With games and interactive information, in particular a tour through the history of the universe, the module offers a perfect introduction to the world of particle physics and shows why basic research is so important for our society.

Presenting DESY research at the Long Night of the Sciences in Berlin-Adlershof

A new view of our cosmic home

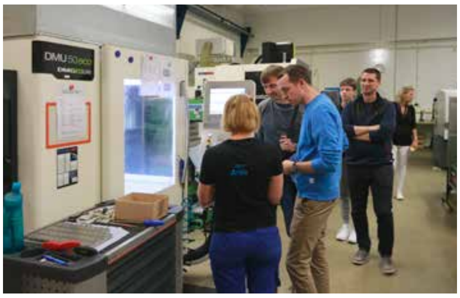
Using the IceCube neutrino observatory at the South Pole, researchers have for the first time detected neutrinos from our home galaxy, the Milky Way. The ghostly cosmic particles provide insights into the energetic processes in which they are created, which cannot be obtained by any other means. The international research team presented its observations in the journal *Science*.

The award-winning Science Communication Lab in Kiel created an interactive module for DESY to visualise the IceCube observations of galactic neutrinos. Viewers can navigate through the neutrino data in the Milky Way and compare the neutrino distribution with electromagnetic radiation from our galaxy at different wavelengths. The IceCube detector can also be explored: https://neutrino-map.science

Visualisation of the IceCube galactic neutrino data

Long Night of Industry

On 30 June, many regional institutions in the Dahme-Spreewald district opened their doors in the evening to provide insights into production halls and the like. DESY in Zeuthen also took part with an extensive programme, which attracted around 400 visitors. Among other things, shopping chips were produced in the workshops and particles turned into music in the experimental hall. Highlights of the visit included guided tours of the computer centre, the PITZ accelerator and the cleanroom.



Presentations at the Long Night of Industry

July

Brandenburg State Secretary Grimm visits Zeuthen campus

As part of his summer trip as Digital Representative of the State of Brandenburg, State Secretary Benjamin Grimm visited the DESY campus in Zeuthen on 6 July. During an extensive tour of the campus, Grimm learned about the progress made at the research centre and gained insights into the dynamic world of quantum computing. DESY and the Brandenburg State Chancellery are working together to promote science, research and technology in the region.

State Secretary Benjamin Grimm (second from left) catching up on latest developments at the Centre for Quantum Technology and Applications (CQTA) at DESY

Exhibition "Beam me up, Potsdam"

On 14 July, the open-air exhibition "Beam me up, Potsdam. Once to the Milky Way and back!" was ceremoniously opened at the Old Market in Potsdam in the presence of Brandenburg Science Minister Manja Schüle. As one of four Brandenburg institutes involved in the realisation of the exhibition, DESY was represented by Christian Stegmann. The exhibition was on display at the Old Market until mid-December and then moved on to Volkspark Potsdam.

Summer student season

On 18 July, 13 students from all over the world arrived on the Zeuthen campus to get a feel for science in the various groups until 7 September. A total of 76 students from 27 countries took part the DESY summer student programme in Hamburg and Zeuthen. The programme included full-time work in the research groups, a lecture programme on DESY research topics and visits to facilities operated by DESY. The students in Zeuthen also enjoyed a guided tour of Berlin and a weekend trip to Hamburg.

The Zeuthen summer students by the lake

August

Doctoral Thesis Award of the German Astronomical Society for Annika Rudolph

Annika Rudolph

DESY PhD student Annika Lena Rudolph was awarded the Doctoral Thesis Award 2023 of the German Astronomical Society for her outstanding PhD thesis. Annika Rudolph, who received her PhD from the Humboldt University of Berlin, was honoured for her work on high-energy astrophysical phenomena, such as gamma-ray bursts, using numerical modelling.

First AstroCamp at DESY – "Balloon mission 2023"

Preparing the launch of the research balloon

From 21 to 24 August, DESY organised its first AstroCamp for young people, the highlight of which was the launch of a research balloon. Twenty young people were invited to explore cosmic particles and determine climate-relevant data, such as the temperature and ozone content of the atmosphere. The balloon flew to an altitude of over 37 900 m, turning the stratosphere into a laboratory.

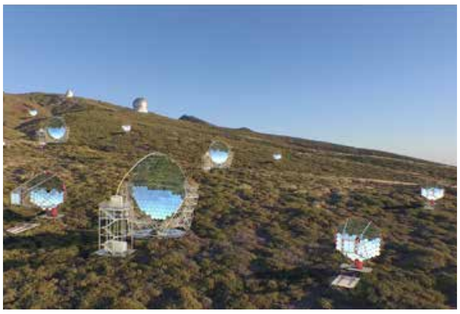
September

ERC Starting Grant for Anna Nelles

The European Research Council (ERC) approved funding for the search for extremely energetic cosmic particles. DESY researcher Anna Nelles, who is also a professor at Friedrich Alexander University Erlangen-Nürnberg, successfully applied for an ERC Starting Grant with DESY as host institution. She will receive 1.5 million euros over the next five years for the construction of a network of radio antennas on Greenland to eavesdrop on extremely energetic neutrinos from space. The Radio Neutrino Observatory Greenland (RNO-G) will be the first large facility of its kind, with 35 stations to be set up by 2026.

Anna Nelles with one of the new mDOMs for IceCube (left) and a radio antenna for RNO-G (right)

CTAO funding increase approved



Artist's rendering of the CTAO North site at an altitude of 2200 m on the island of La Palma

On 6 September, the two CTAO governing bodies – the Board of Governmental Representatives (BGR) and the CTAO gGmbH Council – met to decide on measures to support the next-generation gamma-ray observatory in the construction phase. Both bodies unanimously certified their commitment to the progress of CTAO, including funding of up to around 30 million euros for 2024 – a significant increase in annual funding that will enable the observatory to implement substantial infrastructure measures and double its staff.

Visit of the ULTRASAT project office

On 19–20 September, representatives from the ULTRASAT project office and NASA met at DESY in Zeuthen to discuss the status of the project. ULTRASAT is a scientific satellite mission led by the Weizmann Institute of Science in Israel. It will carry a telescope with an unprecedentedly large field of view, which will be used to conduct the first wide-field survey of transient and variable sources in ultraviolet light (with wavelengths of 230–290 nm). DESY is responsible for developing the telescope camera. The purpose of the meeting was to discuss the overall project schedule as well as the risks and risk mitigation strategies for the camera development at DESY.

ULTRASAT team members with representatives from the ULTRASAT project office and NASA

October

Discovery of highest energy gamma-rays ever from a pulsar

Scientists using the High Energy Stereoscopic System (H.E.S.S.) observatory in Namibia detected the highest-energy gamma rays ever from a dead star called a pulsar. The energy of these gamma rays clocked in at 20 TeV, or about ten trillion times the energy of visible light. This observation is hard to reconcile with the theory of the production of such pulsed gamma rays, as the international team reported in the journal *Nature Astronomy*.

Researchers assume that infrared photons from the poles of the Vela pulsar are boosted to gamma-ray energies (blue) by fast electrons.

Best Flash Talk prize for Nora Feigl

Nora Feigl

Nora Feigl, a PhD student in the DESY Neutrino Astronomy group, won a prize for the Best Flash Talk at the XX International Workshop on Neutrino Telescopes (NuTel) 2023. Her talk focused on the characterisation of intrinsic noise caused by radioactive decays in the glass components of multi-PMT digital optical modules and its impact on the reconstruction of GeV-scale neutrino interactions in the IceCube Upgrade.

Tenth APC meeting

Former and new APC members from left to right: Elena Amato, Stefano Gabici, Marco Cirelli, Jörn Wilms, Marica Branchesi, Jamie Holder, Christian Stegmann (missing: Dorothea Samtleben)

While the ninth meeting of the DESY Astroparticle Physics Committee (APC) was held as a remote event, the tenth APC meeting took place again in person at the Zeuthen campus on 19 and 20 October. Stefano Gabici joined the APC as a new member, while Elena Amato and Marco Cirelli left the committee after their term of office. The APC commended the Astroparticle Physics Division for being internationally competitive and carrying out world-class science and congratulated everyone involved on their achievements.

November

Awards at DESY DAY 2023

At DESY DAY 2023 on 2 November, Annika Rudolph received the PhD Thesis Prize of the Association of the Friends and Sponsors of DESY (VFFD) for her thesis on “Emission of Multiple Messengers from Gamma-Ray Bursts”, together with Dennis Mayer for his work on “Time-resolved X-ray Spectroscopy of 2-Thiouracil”. Stefan Ohm and Olaf Behnke received the DESY Award for Exceptional Achievements for coordinating the first DESY–Ukraine Winter School.

Members of the Astroparticle Physics Division at DESY DAY 2023

Design testing of CTAO MST telescope structure completed

The CTAO Project Office officially declared the Critical Design and Manufacturing Review of the Medium-Sized Telescope (MST) structure passed. At the CTAO General Meeting in Berlin in November, the critical actions raised during the 2022 review were examined and approved. It was an enormous effort for the MST team to close the majority of more than 500 action items raised. One of them involved upgrading the structural design to make it earthquake-resilient for the CTAO South site in Chile, which required extensive engineering efforts. The passing of the review is a major milestone that marks the official start of the procurement, preassembly and deployment of the first two CTAO Pathfinder telescopes.

International Cosmic Day

On 21 November, the International Cosmic Day (ICD) took place for 12th time, organised by DESY in Zeuthen. The ICD is dedicated to the unnoticed cosmic particles that flood our universe and constantly surround us on Earth. On this day, schools, universities and research institutions in 18 countries on four continents enabled young people all over the world to learn more about these particles from the cosmos, explore them and exchange their newly acquired knowledge in joint video conferences, supported and guided by scientists and teachers.

December

CTAO Consortium Meeting in Berlin

The CTAO Consortium meeting took place in Berlin at the beginning of December. The agenda included construction-related software and hardware projects, comprising updates on the data model, array control software, telescopes and site development schedule.

Participants of the CTAO Consortium meeting in Berlin

Astroparticle physics

Astroparticle physics at DESY rests on three pillars: (i) observations of gamma rays, (ii) observations of neutrinos and (iii) their interpretation and understanding through astroparticle physics theory. Gamma rays and neutrinos are neutral messengers that are not deflected by magnetic fields on their way to Earth and therefore point back to their sources, allowing astronomical observations to be carried out. Further undeflected messengers are photons at smaller energies (radio waves to X-rays) and gravitational waves. In their contemporaneous observation and combination lies great strength, which will increasingly drive progress in our understanding of the astrophysics of the most violent objects and events in the universe.

Artist's impression showing how a series of pulsars are affected by gravitational waves coming from a pair of supermassive black holes from a distant galaxy.

Experiments, theory, projects and infrastructures

Energy-dependent morphology of SS 433 microquasar jets seen in very-high-energy gamma rays

Uncovering highly efficient particle acceleration in the parsec-scale outer jets of a microquasar in the Milky Way

The microquasar SS 433 is a binary system in our galaxy, which consists of a black hole that accretes material from its companion supergiant star, launching double-sided jets. Its inner jets extend to ~0.1 pc from the compact object. At distances of ~25 pc up to ~100 pc, X-ray emission along the jet axis indicates the presence of a recollimated outflow: the outer jets. In a study with key participation of DESY, the High Energy Stereoscopic System (H.E.S.S.) in Namibia detected very-high-energy (VHE) gamma-ray emission correlating with the outer jets. It exhibits an energy-dependent morphology in the TeV range, pointing to a leptonic radiation process, with the sites of acceleration constrained to the base of the parsec-scale jets. This requires the presence of a strong shock at >25 pc, resulting from the self-collimation of the inner jets.

In a nutshell

The microquasar SS 433 is a puzzling source in the Milky Way, with two jets – i.e. collimated beams of particles – launched in opposite directions from the central compact object. Compared to other known extragalactic jets, it is located close to Earth, with a geometry that facilitates observation of the outflow region. As the first observed object of a (possible) new class of VHE gamma-ray sources – VHE microquasars – its proximity, its jet dynamics and its observed emission make SS 433 a "local" system for studying shock and plasma physics.

In a study led by the Max Planck Institute for Nuclear Physics in Heidelberg and the DESY Astroparticle Physics Theory group in Zeuthen, the microquasar was investigated by means of dedicated observations by H.E.S.S. and using novel analysis techniques, allowing the first detection of TeV gamma rays from SS 433 by an imaging atmospheric Cherenkov telescope. In addition, the emission was modelled with a 1D advection-driven simulation, which was used to characterise the flow properties. The presence of a strong shock was derived, which could explain the accelerated electrons and positrons behind the observed TeV radiation. The results [1, 2], which were published in *Science* in January 2024, testify to the ongoing efforts of the H.E.S.S. collaboration, which also involve the H.E.S.S. group at DESY, with members in the DESY Astroparticle Physics Theory group and the DESY Gamma Astronomy group.

Inner and outer jets of SS 433

SS 433 is a stellar binary system in the Milky Way, embedded in the radio supernova remnant W 50, a large cloud formed when its progenitor star exploded 10 to 100 thousand years ago [3, 4]. SS 433 consists of a compact object, likely a black hole with around ten solar masses, orbiting with its companion Type A star with a period of around 13 days [5]. Through the action of its gravitational field, the black hole accretes material from the surface of the star, which accumulates in a disc of hot gas. As matter is pulled in towards the black hole, two collimated jets of charged particles are launched perpendicular to the plane of the disc, with a velocity of ~0.26 c [5, 6]. Based on their position coordinates in the celestial sphere with respect to the central binary, these jets are referred to as the "eastern" and "western" jets.

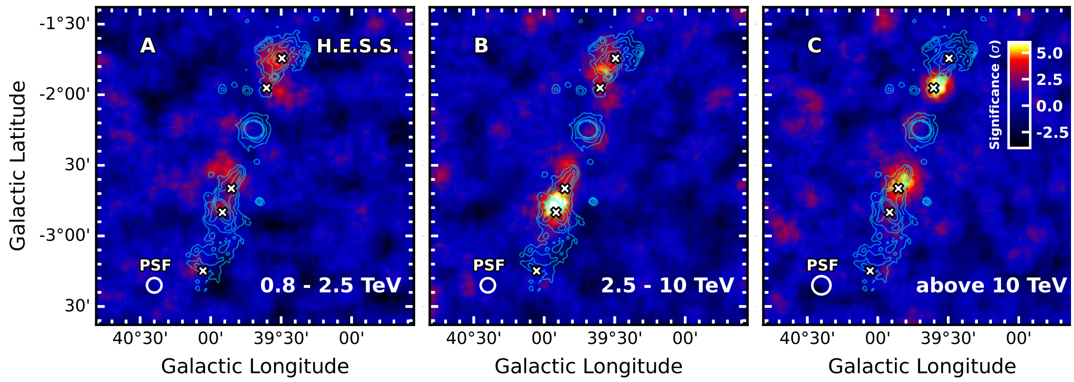


Figure 1
Significance maps of VHE gamma-ray emission in energy bands:
(A) 0.8–2.5 TeV,
(B) 2.5–10 TeV and
(C) >10 TeV.
Cyan contours: X-rays [8, 9].
White crosses: locations of bright X-ray regions.
The white circle indicates the 68% containment region of the H.E.S.S. point-spread function (PSF).

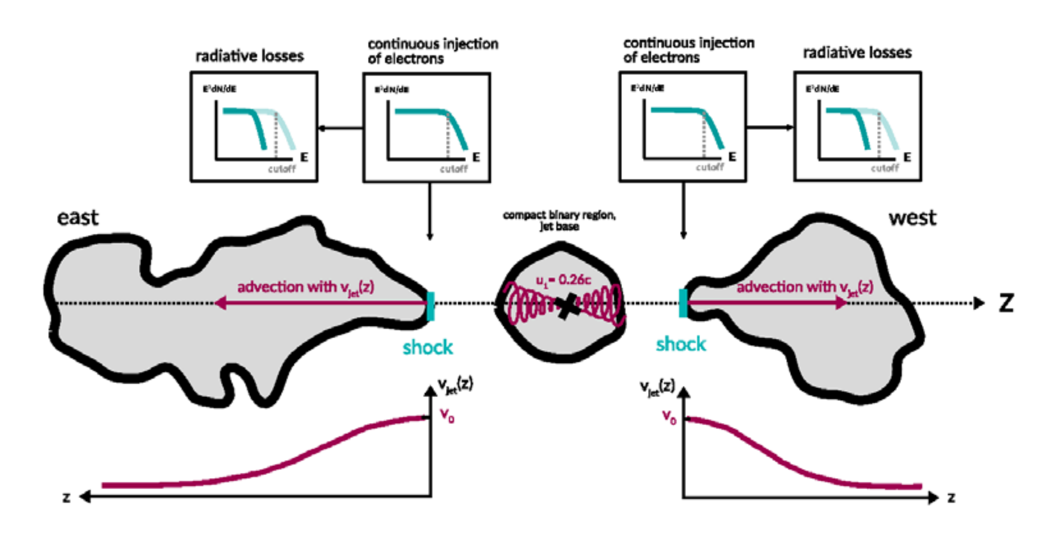


Figure 2
Schematic of a 1D model for the jet outflows. The inner jet is launched with velocity $u_1 \approx 0.26\,c$ (spirals) and reaches a shock discontinuity (cyan bars) at the base of the outer jets. There, electrons are injected continuously, with an energy spectrum derived from fitting multiwavelength observations, accounting for radiative losses. Particles are transported along the jet axis z through advection and diffusion with $v_{jet}(z)$ [2].

In radio and optical observations, using 5.5 kpc as the measured distance to the system [5], the emission extends from 0.001 pc in the vicinity of the compact object up to ~0.1 pc: These are the so-called inner jets. They are oriented perpendicular to the line of sight and precess with a half-opening angle of 20 degrees and a period of around 162 days [7]. At distances of ~25 pc up to ~100 pc, bright X-ray synchrotron emission along the jet axis [8, 9] indicates the presence of a recollimated outflow: the outer jets.

Similar relativistic jets are also observed emanating from the centres of active galactic nuclei (such as quasars), though their lengths scale up to several kiloparsecs, i.e. considerably larger than the galactic jets of SS 433. Because of this analogy, objects such as SS 433 are classified as microquasars. In 2018, the High-Altitude Water Cherenkov Gamma-ray (HAWC) observatory in Mexico purported the detection of two "hotspots" at 20 TeV, coinciding with the X-ray emission of the eastern and western jets [10]. However, the angular resolution could not provide further insight into the morphology of the detected emission, nor could it exclude possible source confusion with the also-bright gamma-ray source MGRO 1908+06 (HESS J1908+063) in the western region of the field of view. In addition, the HAWC data at the time were not of sufficient significance to constrain the spectral index of the emission.

H.E.S.S. results
H.E.S.S. is an array of Cherenkov telescopes located in Namibia, which has been operating since 2003. After a deep observation campaign, resulting in over 200 hours of exposure time, and using a higher-energy optimisation analysis technique aimed at faint sources [11], H.E.S.S. has now also detected two sites of extended gamma-ray emission at the previously known X-ray positions of the eastern and western jets, with significances of 7.8 σ and 6.8 σ, respectively [2]. No significant emission (>5 σ) was detected from the central binary, only constraining upper limits have been derived. Thus, an imaging atmospheric Cherenkov telescope has confirmed the HAWC detection and characterised the emission associated with the jets. Preliminary results from the VERITAS gamma-ray instrument, another imaging atmospheric Cherenkov telescope located in the USA, with a study led by members of the DESY Gamma Astronomy group, are in preparation.

Furthermore, H.E.S.S. analyses in different energy bins have revealed a statistically significant energy-dependent morphology: As can be seen in Fig. 1, there is a shift of the centre of the gamma-ray emission towards the base of the outer jet as a function of energy. When modelling the emission, a leptonic scenario for the radiation process is preferred, which is consistent with the energy dependence: inverse Compton scattering of energetic electrons on target photon fields. While a hadronic contribution is not completely excluded, it is not supported by current observational signatures. Based on the energy-dependent offset of the gamma-ray emission, the sites of particle acceleration are constrained to the base of the outer parsec-scale jets and require an abrupt deceleration of the flow to exist there. To explain the properties of the emission, the presence of a strong shock at 25–30 pc on either side of the system is inferred, resulting from the self-collimation of the precessing inner jets. Figure 2 shows a diagram of the model proposed to explain the characteristics of the emission. More details can be found in [2] and in an outreach video of the results [12].

Author contact:
Michelle Tsirou, *michelle.tsirou@desy.de*

References:

[1] L. Olivera-Nieto, PhD Thesis, Ruprecht-Karls-Universität, Heidelberg (2023)
[2] H.E.S.S. Collaboration, L. Olivera-Nieto, B. Reville, J. Hinton, M. Tsirou et al., Science 383, 402–406 (2024)
[3] P. T. Goodall, F. Alouani-Bibi, K. M. Blundell, Mon. Not. R. Astron. Soc. 414, 2838–2859 (2011)
[4] M. G. Bowler, R. Keppens, Astron. Astrophys. 617, A29 (2018)
[5] K. M. Blundell, M. G. Bowler, Astrophys. J. 616, L159 (2004)
[6] B. Margon, H. C. Ford, S. A. Grandi, R. P. S. Stone, Astrophys. J. 233, L63 (1979)
[7] A. C. Fabian, M. J. Rees, Mon. Not. R. Astron. Soc. 187, 13P–16P (1979)
[8] W. Brinkmann, B. Aschenbach, N. Kawai, Astron. Astrophys. 312, 306 (1996)
[9] S. Safi-Harb, H. Ögelman, Astrophys. J. 483, 868–881 (1997)
[10] HAWC Collaboration, Nature, 562, 82–85 (2018)
[11] L. Olivera-Nieto, H. X. Ren, A. M. W. Mitchell, V. Marandon, J. A. Hinton, Eur. Phys. J. C 82, 1118 (2022)
[12] https://www.youtube.com/watch?v=gsVb96q-KRw

A break in the extragalactic neutrino spectrum

Novel analysis of IceCube data enables most precise measurement of cosmic neutrino spectrum to date

Most of the cosmic neutrinos observed by the IceCube detector at the South Pole are of extragalactic origin. Measuring their spectrum can provide important clues about the nature of the environments in which they are produced. High-energy neutrinos generate two main signatures in the detector: tracks and showers, depending on the flavour of the incoming neutrino. A novel analysis developed mainly at DESY and RWTH Aachen combines these two main signatures of neutrinos into a single measurement while accounting for their highly correlated systematic uncertainties in a self-consistent way. This approach enables the most accurate measurement of the cosmic neutrino spectrum to date. For the first time, evidence has been found for a break in the spectral shape, demonstrating that the neutrino spectrum is more complex than a single power law.

Introduction

The discovery of astrophysical neutrinos over a decade ago established a new branch of multimessenger astronomy. Combining the information from neutrinos with astrophysical observations across the electromagnetic spectrum allows us to study cosmic particle accelerators in a complementary way. In particular, neutrinos can give us a glimpse into environments that are opaque to electromagnetic radiation, such as the regions close to the central supermassive black holes of active galaxies. In such active galactic nuclei (AGN), the intense radiation from an accretion disk that surrounds the black hole, together with dense dust and gas clouds, efficiently blocks large portions of the electromagnetic spectrum. Neutrinos are unaffected by such obstacles and reach us even from regions close to the event horizon of the black hole.

NGC 1068 is the first AGN identified by IceCube as a neutrino source [1]. However, its emission only accounts for a tiny fraction of the observed cosmic neutrinos. The vast majority of neutrinos appears to form a quasi-diffuse emission that most likely originates from many unresolved sources, too dim to be identified individually by IceCube. While we do not currently know which classes of astrophysical neutrino sources produce them, we can now state that about 90% of these neutrinos are extragalactic in origin [2].

Figure 1
Two active galaxies (NGC 4151 and NGC 4156) observed through an 81 cm telescope. Such galaxies are typical neutrino source candidates. Neutrino sources that are too faint to be identified individually contribute to the diffuse extragalactic neutrino flux.

Figure 1 shows an optical image of two active galaxies. Neutrinos from high-energy cosmic-ray interactions in such galaxies might contribute significantly to the diffuse emission, while individual objects are not luminous enough to be detected as neutrino sources.

Measurement of the extragalactic neutrino spectrum

The spectrum of the diffuse neutrino emission can provide important additional information on the sources of the neutrinos and the physical processes relevant for their production. A novel analysis, developed mainly at DESY and RWTH Aachen in Germany, has now achieved the most precise measurement of this spectrum to date. This was made possible by combining about a decade of observations of the two most important signatures of high-energy neutrinos in IceCube, tracks and showers.

Figure 2 shows typical observed Cherenkov light patterns for both types of events. In the past, several measurements have derived the astrophysical neutrino spectrum for each channel separately, which limited the accuracy achieved (e.g. [3, 4]). A first combination of track and shower channels based on early IceCube data was developed at DESY and published in 2015 [5]. Although it was the best measurement at that time, it relied partly on data obtained during the construction phase of IceCube and did not have access to uniformly calibrated and processed data and a uniform detector simulation. Systematic measurement uncertainties, such as the optical properties governing the propagation of the Cherenkov light in the ice, or the spectrum and flux of the atmospheric neutrino background are highly correlated for all observed

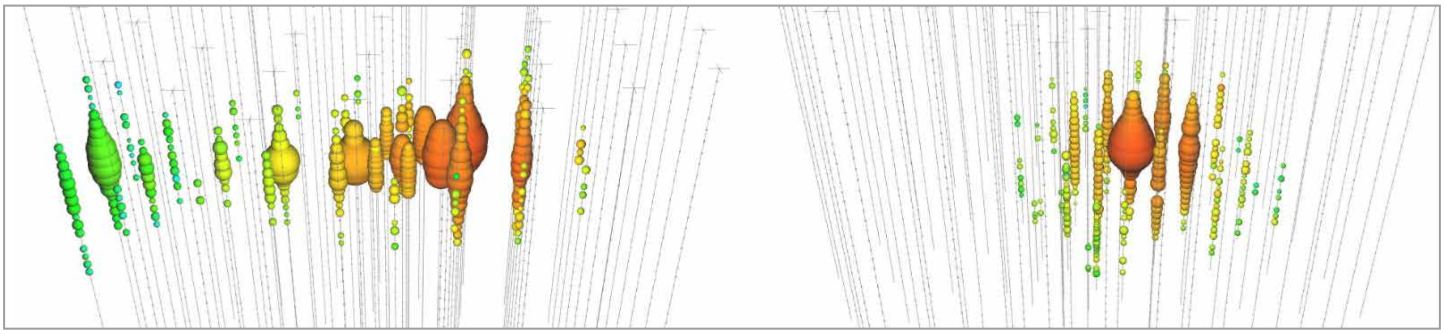


Figure 2
The two main signatures of neutrinos observed in the IceCube detector. Left: Tracks arise from interactions of muon neutrinos in and around the instrument. The muon produced in the interaction typically travels several kilometres in the ice and generates Cherenkov light along its path. Right: Showers arise from interactions of all flavours of neutrinos, where charged particles generated in the neutrino interaction deposit their energy and produce Cherenkov light only over a very short distance. Each dot marks an optical sensor of IceCube. The colour indicates the measured light arrival time, and the size of the dot denotes the amount of light observed.

neutrino signatures. The current analysis now addresses for the first time such correlations in a self-consistent way. Together with the much larger data set – comprising more than one decade of observations of the completed IceCube detector, all processed and calibrated in a uniform way – this enabled the derivation of the most precise neutrino spectrum to date.

A break in the cosmic neutrino spectrum
Figure 3 shows the spectrum obtained above about 5 TeV. It is consistent with earlier measurements. However, the higher precision allows more sensitive testing for spectral features than ever before. The most striking new feature observed is a break in the power law behaviour of the spectrum around 30 TeV. A likelihood ratio test, which tests such a broken power law spectrum against the hypothesis of a power law without a break, finds that the broken power law is preferred with a significance of 4.2 σ.

This is the first time that IceCube data provide strong evidence that a simple power law does not properly describe the spectrum of high-energy cosmic neutrinos. The best-fit broken power law spectrum also aligns well with a fit of the neutrino flux in individual energy bands that does not rely on a specific model of the spectral shape.

Potential implications for sources of high-energy neutrinos
What does this result tell us about the origin and production mechanisms of cosmic neutrinos? First, it means that there are fewer neutrinos at low energies (<10 TeV) than expected for a power law spectrum. This helps to resolve an often-discussed tension between the extragalactic gamma-ray and neutrino backgrounds (e.g. [6]), as both particles are produced simultaneously in high-energy cosmic-ray interactions. Second, it might also be indicative of a photo-hadronic production of the neutrinos (e.g. [7]), meaning that the cosmic rays in the unknown sources collided with photons rather than with clouds of gas. This process has a comparatively low cross section and therefore only efficiently produces neutrinos in the most intense photon fields of the universe, such as the jets or the vicinity of the accretion disks of AGN (while being much smaller than our solar system, AGN accretion disks typically produce more radiation than the entire Milky Way).

The combined measurement also paves the way for better constraints of the flavour composition of astrophysical neutrinos with IceCube data in the near future, a measurement that represents a unique probe of physics beyond the Standard Model (e.g. [8]).

Further reading
More details about the results can be found in [9] and [10]. A journal publication is in preparation within the IceCube collaboration.

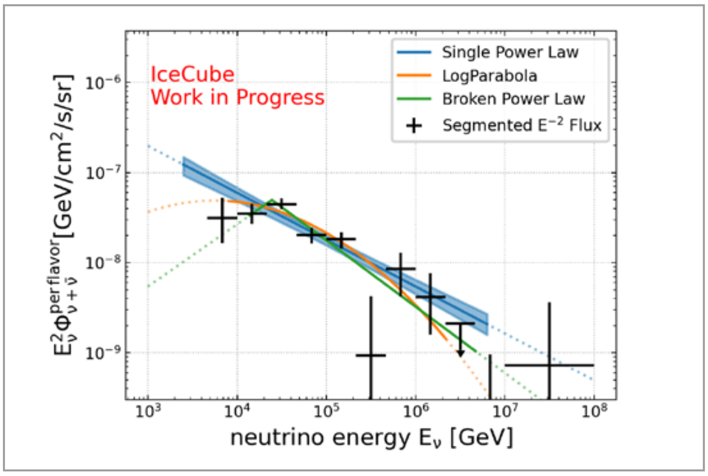


Figure 3
The latest IceCube measurement of the cosmic neutrino flux shows clear evidence of a break in the spectrum around a neutrino energy of 30 TeV. A single power law spectral model, indicated by the blue band, is disfavoured by more than 4 σ compared to the best-fit broken power law. From [9].

Author contact:
Markus Ackermann, *markus.ackermann@desy.de*

References:

[1] IceCube Collaboration, R. Abbasi et al., Science 378, 538–543 (2022)
[2] IceCube Collaboration, R. Abbasi et al., Science 380, adc9818 (2023)
[3] IceCube Collaboration, M. Aartsen et al., Phys. Rev. Lett. 125, 121104 (2020)
[4] IceCube Collaboration, R. Abbasi et al., Astrophys. J. 928, 50 (2022)
[5] IceCube Collaboration, M. Aartsen et al., Astrophys. J. 809, 98 (2015)
[6] K. Murase, M. Ahlers, B. Lacki, Phys. Rev. D 88, 121301 (2013)
[7] K. Murase, D. Guetta, M. Ahlers, Phys. Rev. Lett. 116, 071101 (2016)
[8] M. Bustamante, J. Beacom, W. Winter, Phys. Rev. Lett. 115, 161302 (2015)
[9] R. Naab, E. Ganster, Z. Zhang, PoS ICRC2023, 1064 (2023)
[10] R. Naab, PhD thesis, submitted to Humboldt University of Berlin (2024)

Unlocking the mystery of distant blazars' cascades

Explaining the gamma-ray observations of blazars: insights from plasma physics

Gamma rays emitted by distant blazars generate beams of electron–positron pairs. These pairs are expected to produce a secondary cascade emission that we can detect. However, this cascade is absent in gamma-ray observations. This absence is attributed to two possible factors: Either the pairs are diverted by intergalactic magnetic fields (IGMFs), or they are losing energy due to plasma instability. In a recent study, researchers from the DESY Astroparticle Physics Theory group have combined the two factors for the first time. They discovered that the broadening of the pair beam opening angles by IGMFs diminishes the energy loss from instability. Furthermore, in a separate study, they found that the self-consistent feedback of instability on the beam suppresses the instability by beam broadening as well.

Introduction

Blazars are active galactic nuclei (AGN) with the jet of the supermassive black hole pointing at Earth. Figure 1 shows an example of such an AGN. We know from the observations of imaging atmospheric Cherenkov telescopes, i.e. VERITAS, MAGIC and H.E.S.S., that blazars produce a bright emission of gamma rays in the GeV to TeV energy band. However, the TeV gamma rays from distant blazars don't travel freely in the universe. They annihilate with the extragalactic background light (EBL), producing a collimated beam of electron–positron pairs. The pair beams are expected to dissipate their energy through inverse Compton scattering on the cosmic microwave background (CMB), producing an electromagnetic cascade in the GeV energy range. Figure 2a shows those different interaction processes, starting from the primary TeV gamma rays and ending with the secondary GeV cascade.

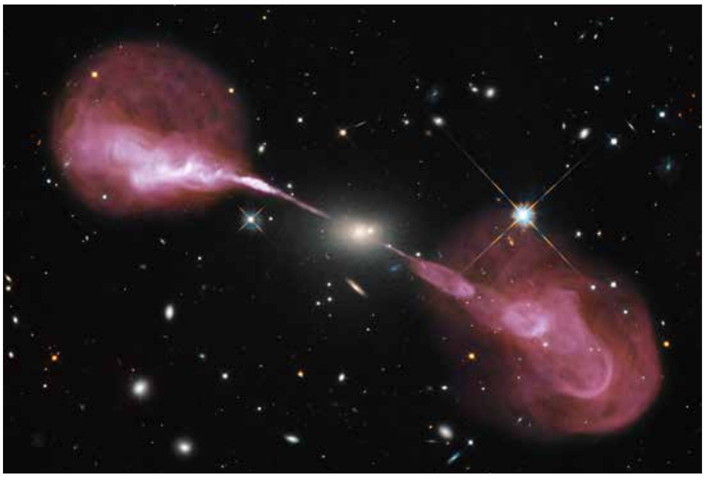


Figure 1

Multiwavelength image of AGN 3C 348 (Hercules A).
The Hubble Space Telescope spots the yellow elliptical galaxy in visible light, while the Karl G. Jansky Very Large Array (VLA) radio telescope in the USA reveals its pink jets in radio waves.

Around 15 years ago, the Large Area Telescope on board the Fermi Gamma-ray Space Telescope (Fermi-LAT) discovered that the secondary GeV cascade was missing in the blazars' spectra. Currently, there are two mechanisms that offer a potential explanation for this cascade suppression. The first involves the deflection of the pair beam by IGMFs present in the cosmic voids between us and the blazar [1]. This deflection leads to a decrease in the secondary cascade emission that reaches us, aligning with the spectra of the observed blazars. The second mechanism is an energy loss of the pair beam due to plasma instability before the beam generates the secondary cascade [2]. Figures 2b and 2c illustrate these two mechanisms.

Intergalactic magnetic fields affect instability

Previous studies of blazar-induced cascades often focused solely on IGMFs or on instability, neglecting either one or the other. In contrast, researchers from the DESY Astroparticle Physics Theory group have now explored both factors simultaneously for the first time [6]. They discovered that IGMFs broaden the opening angles of pair-beam particles, thereby significantly reducing the effectiveness of beam energy loss due to instability. Furthermore, their findings indicate that instability is eliminated as an efficient energy loss agent at a field strength three orders of magnitude lower than that required to suppress the secondary cascade emission through magnetic deflection.

Figure 3 shows the allowed IGMF parameter regions (white areas). Above the purple line, the energy loss through instability is subdued by the IGMFs. Below the green line, the IGMFs lack the strength to suppress cascade emission [4]. For IGMF parameters between the purple and green lines, no viable process explains the absence of GeV-scale cascade emission, thus excluding this IGMF parameter space region (cyan-shaded area).

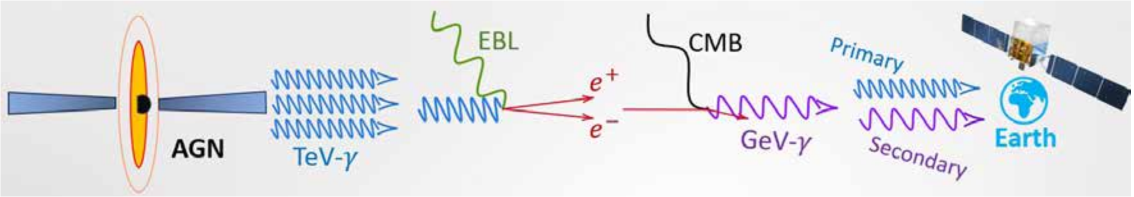


Figure 2a
Blazar-induced cascade generation mechanism

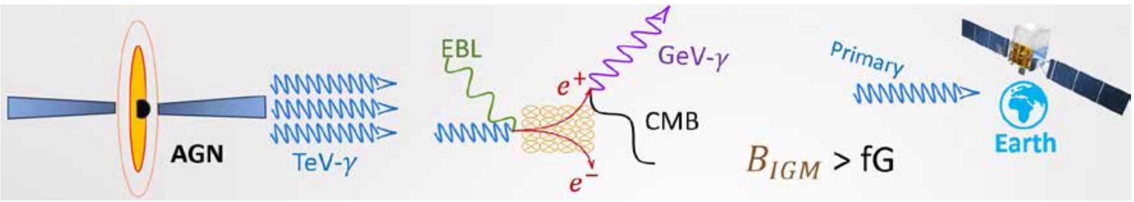


Figure 2b
Suppression of the cascade through pair deflection by IGMFs

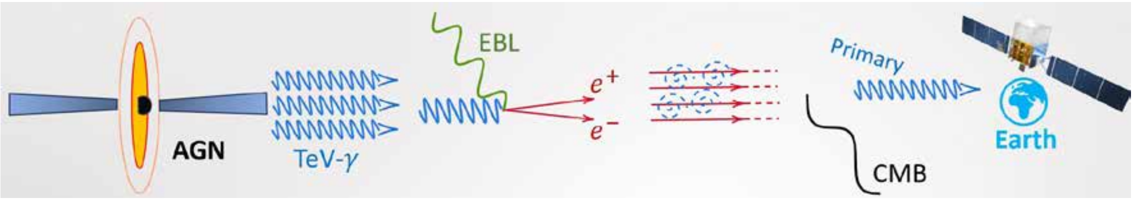


Figure 2c
Suppression of the cascade through energy loss of the pairs due to plasma instability

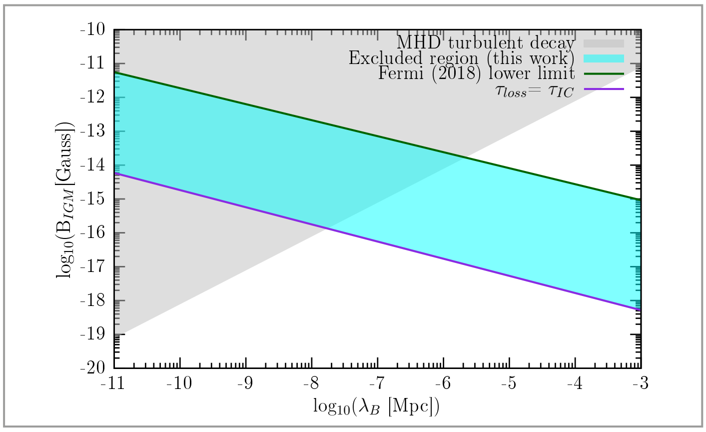


Figure 3
The cyan-shaded area represents the excluded region of the IGMFs, where neither magnetic deflection nor instability can account for the absence of cascade emission. The grey region indicates the upper limit on the IGMF strength due to magnetohydrodynamic (MHD) turbulent decay [3]. From [6].

Feedback of instability on the beam

In another recent study [7], researchers from the DESY Astroparticle Physics Theory group investigated how plasma instability feeds back on the beam, using a realistic two-dimensional beam distribution. The instability feedback on the beam was examined through two non-linearly coupled equations, which describe the time evolution of both the beam and the plasma waves. These theoretical calculations pose significant challenges and can only be tackled numerically. The physics governing this non-linear feedback requires a resolution of the time scales down to a few years, while the development of the secondary cascade occurs over scales larger than hundreds of thousands of years. The calculations of the instability feedback were conducted at a distance of 50 Mpc from the blazar, where the majority of the cascade energy is expected to be generated.

In this new study, it was discovered that the predominant effect is a broadening of the beam with little energy loss. These recent findings validate a previous feedback study with a simplified setup [5], contradicting the notion that instability serves as an effective energy loss mechanism for the pair beam, which was proposed to explain the absence of the secondary cascade. However, the latest research suggests that the broadening of the beam opening angles due to instability feedback could have observational implications for the secondary cascade emission too [7].

This latest work also suggests that, once accounting for the continuous creation of pairs by the TeV gamma rays, the beam and the plasma waves reach a new quasi-steady state. In this state, the broadening of the beam opening angles by instability persists, increasing the beam opening angle by a factor of hundreds. This leads to a time delay of approximately 10 years for the arrival of the secondary cascade, produced at a distance of 50 Mpc from the blazar, compared to the primary gamma rays. Understanding the implications for the observed GeV cascade emission at Earth requires calculating the beam broadening by instability at various distances between us and the blazar.

Summary

The recent studies revise our comprehension of plasma instability as an effective energy loss mechanism of blazar-induced pair beams. The instability is suppressed by the broadening of the beam opening angles either by pre-existing IGMFs [6] or by the instability itself [7]. Nevertheless, the beam broadening by instability might have observational implications for the arrival time of the secondary cascade emission. Further studies, including calculations of the beam broadening by instability at various distances between us and the blazar, would provide clarity on this matter.

Author contact:
Mahmoud Alawashra, *mahmoud.al-awashra@desy.de*

References:

[1] A. Neronov, I. Vovk, Science 328, 73 (2010)
[2] A. E. Broderick et al., Astrophys. J. 752, 22 (2012)
[3] R. Durrer, A. Neronov, Astron. Astrophys. Rev. 21, 62 (2013)
[4] M. Ackermann et al., Astrophys. J. Suppl. S. 237, 32 (2018)
[5] R. Perry, Y. Lyubarsky, Mon. Not. R. Astron. Soc. 503, 2215 (2021)
[6] M. Alawashra, M. Pohl, Astrophys. J. 929, 67 (2022)
[7] M. Alawashra, M. Pohl, Astrophys. J. 964, 82 (2024)

Astrophysical Multi-Messenger Modeling (AM^3)

Open-source tool for time-dependent lepto-hadronic modelling of astrophysical sources

In the era of multimessenger astroparticle physics, our understanding of high-energy astrophysical sources builds on a growing wealth of data not only across the electromagnetic spectrum, but also in the cosmic-ray and neutrino domains. The recent progress on the observational side calls for similar maturity on the modelling side. A team of DESY scientists has therefore developed a time-dependent, lepto-hadronic source modelling software called Astrophysical Multi-Messenger Modeling, or AM^3. It is fast, its component tracking allows for great intuition, and its modular nature opens a window for a broad range of applications. After verification in multiple science cases, including blazars [1, 2], gamma-ray bursts (GRBs) [3, 4] and tidal disruption events (TDEs) [5], the code has been made publicly available [6], including a user-friendly documentation with examples [7].

Typical multimessenger challenge

Figure 1 shows the information flow for a typical multimessenger challenge: Starting from a reservoir of particles and energy (e.g. a shock), some particles (e.g. protons or electrons) get accelerated to non-thermal energies. These cosmic rays subsequently dissipate a fraction of their energy to photons (e.g. gamma-rays) and neutrinos. All of this is typically called source modelling. A fraction of these cosmic rays, neutrinos and photons escapes from the source, undergoes a possibly complicated propagation to Earth and is detected by means of often different detection mechanisms. Each of these steps comes with unique challenges that require detailed study. AM^3 is the puzzle piece that adds the necessary self-consistent treatment for the energy dissipation step.

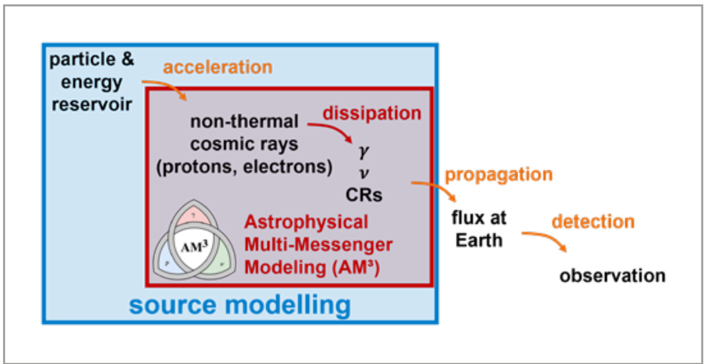


Figure 1
Typical workflow in multimessenger physics, from the initial reservoir of particles and energy to the eventual signatures in the detector

Tracking the energy flow

The process of energy dissipation can be modelled by tracking the flow of particles from one species to lower energies and different species through different interaction channels. For example, this can be high-energy cosmic rays that give part of their energy to neutrinos via collisions with low-energy photons. AM^3 provides a well-tested implementation of this flow for a broad range of energies. It can therefore self-consistently capture the feedback from low-energy particles on the ones at highest energies (and vice versa), and also between different species. AM^3 contains all the relevant channels, i.e. physical processes, that are needed for the typical conditions in astrophysical sources.

The left panel of Fig. 2 provides an example from a recent application of AM^3 to the afterglows of GRBs [4], where a radiation zone moves at relativistic speed towards the observer. The panel shows the observed spectrum of escaping photons (black) and neutrinos (grey) when assuming that protons and electrons are accelerated simultaneously. Besides the total flux, AM^3 also makes it possible to trace the contribution of different processes, such as the synchrotron emission of primary electrons (shaded blue, dominant below about 10 GeV) or the synchrotron radiation of primary protons (shaded yellow, dominant from 10 GeV to 10 PeV). This capability enables a far deeper level of understanding of the obtained results. As can be seen from the multiple other subdominant components, it also allows for excluding the relevance of other possible effects.

The right panel of Fig. 2 shows the corresponding densities of the injected protons and electrons when they reach their steady state and, similar to the photon case, also the contribution of secondary particles produced by interactions between the different primary particles and their secondary products. These include for example pions, which then further decay into muons, which decay into electrons. A by-product is the creation of neutrinos, as shown in the left panel of the figure.

In summary, AM^3 allows the combined determination of cosmic rays, neutrinos and photons, which can then be propagated to Earth and compared to combined multimessenger observations.

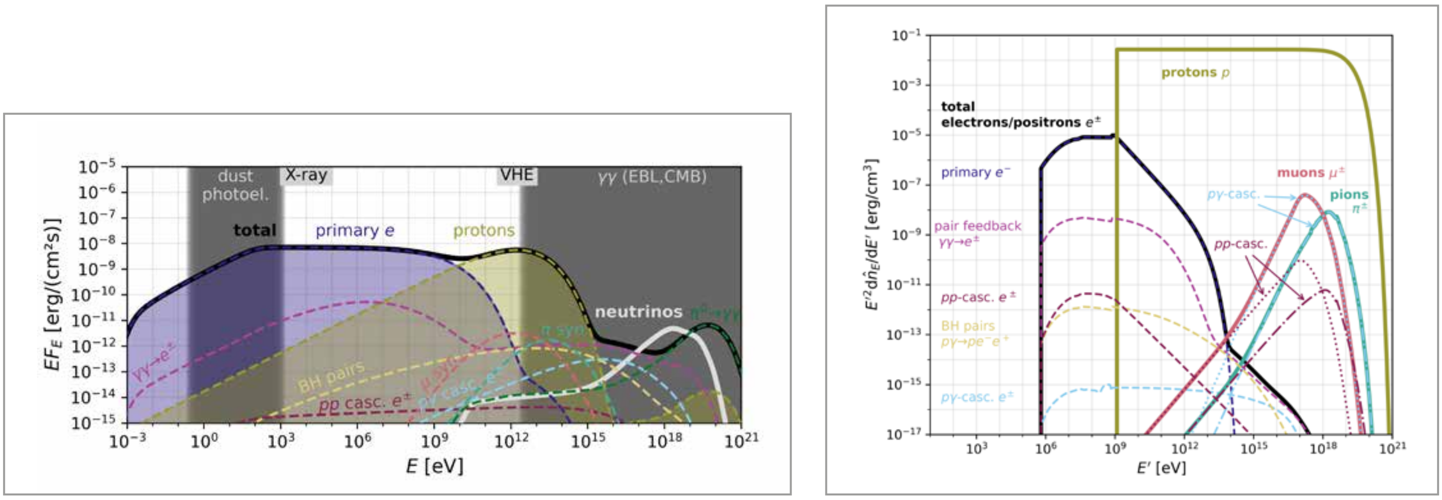


Figure 2
Left: Observed spectral energy distribution of photons and neutrinos (after escaping from the source) for an example from an application of AM³ to GRB afterglows. The grey shaded energy windows show where the photons are strongly absorbed during their propagation. The dashed lines indicate the different contributions to the total photon spectrum. Right: Corresponding particle densities of protons, electrons/positrons, pions and muons in the source region, as well as their components from different channels. Adapted from [4].

Efficiency matters

As source models often involve five to ten free parameters, fast runtime is crucial to enable an exhaustive exploration of the parameter space. This is one of the advantages of AM³, illustrated in Fig. 3. Leptonic scenarios on the left, i.e. without accelerated protons, involve less possible channels and are therefore very fast (a typical case takes less than a second on a single CPU). The multiple channels introduced by non-thermal protons, inducing cascades via pions and muons, increase the runtime. Figure 3 shows how the simulation time depends on the size of the proton energy grid, which determines the size of the matrices that have to be multiplied internally. Remarkably, even for ultrahigh-energy cosmic rays, the computation takes less than 10 s, which enables large parameter scans with AM³.

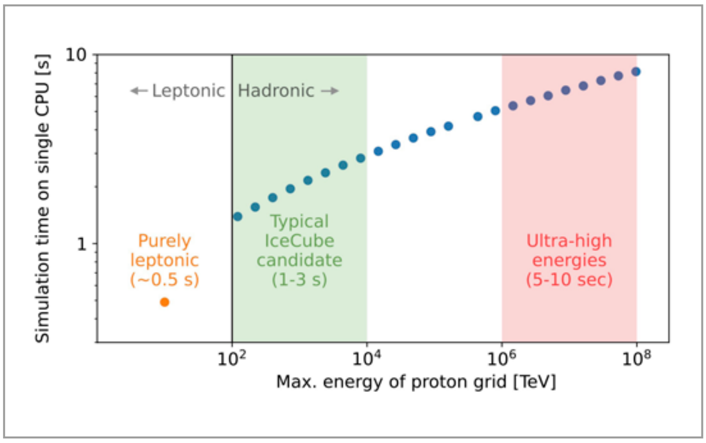


Figure 3
Runtime of the AM³ simulation of a steady-state spectrum for a typical blazar case on a single CPU as a function of the size of the grid determined by the maximum proton energy. A leptonic reference case is given on the left for comparison. From [6].

Flexibility

One special feature of the AM³ implementation is that it combines the best of two worlds. The source code is written in C++, which makes it very fast and accessible for C++ users. In addition, the Python interface allows for simple access via Python without loss of the advantages from C++. Besides this technical flexibility, the modular nature, with access to all particle density arrays and interfaces to inject arbitrary spectra for each species, enables straightforward extensions for coupling AM³ either to multiple instances of itself (e.g. multizone modelling) or to other codes to capture even wider ranges of applications (e.g. cosmic rays with higher mass number). May the publication of this tool illuminate the future of multimessenger modelling with unprecedentedly accurate photons, neutrinos and cosmic rays!

Author contact:
Marc Klinger, *marc.klinger@desy.de*

References:

[1] S. Gao et al., Astrophys. J. 843, 109 (2017)
[2] X. Rodrigues et al., Astrophys. J. Lett. 874, L29 (2019)
[3] A. Rudolph et al., Astrophys. J. Lett. 944, L34 (2023)
[4] M. Klinger et al., submitted to Astrophys. J., arXiv:2403.13902 (2024)
[5] C. Yuan, W. Winter, Astrophys. J. 956, 30 (2023)
[6] https://gitlab.desy.de/am3/am3
[7] M. Klinger et al., Astrophys. J. Suppl. S. 275, 4 (2024)

Venturing into the stratosphere – young people unlock the mysteries of cosmic rays

DESY's first AstroCamp

DESY's inaugural AstroCamp, held from 21 to 24 August 2023 at Lake Werbellin in Brandenburg, offered young students a collaborative environment to conduct their own experiments on cosmic rays in a truly exceptional setting. The camp was organised in collaboration with the association NaWi School e.V. Mentored by two DESY colleagues and teachers from the association, the students enjoyed the fascination and fun of science throughout the week, which culminated on Wednesday, 23 August, in its scientific highlight: the successful launch of a research balloon into the stratosphere. The participants analysed climate-relevant data and cosmic particles recorded during the balloon flight. Some of their findings, showcased alongside a self-made video encapsulating their AstroCamp experience, are highlighted in this article.

Astrophysics holds many intriguing questions, not only for scientists, but also to inspire and foster young people's interest in STEM subjects. This is one of the reasons why DESY has been offering students the opportunity to carry out small research projects in astroparticle physics in its CosmicLab in Zeuthen [1] since 2004. Building on this legacy, efforts have been intensified with DESY's first AstroCamp [2], entitled "The balloon mission 2023 – venturing into the stratosphere with our own research balloon".

AstroCamp – the concept

At the AstroCamp, DESY invited 16 young people aged 16 and over to delve into the mysteries of the cosmos and the Earth's atmosphere. The event aimed to inspire scientific curiosity by giving the students an authentic glimpse into scientific work using modern measurement and analysis methods in a research-like environment. The comprehensive programme started with a kick-off meeting in July on the DESY campus, where participants got to know each other, explored cosmic rays using a DIY cloud chamber and gained insights into DESY's research activities.

The research camp itself took place from 21 to 24 August at Lake Werbellin. The students were able to experience the fascination and fun of science by conducting their own research experiments on cosmic rays, with sufficient room for reflection and discussion, fostering an environment of exploration and collaboration. The scientific programme culminated in the launch of a research balloon into the stratosphere. Afterwards, the participants analysed the recorded data, discussed their results and presented their findings at the International Cosmic Day [3], which was held in November.

Preparing the launch of the balloon

Before the launch, the mission had to be well prepared. One of the students' tasks was to build their own cosmic probe – a flying laboratory that would hold all the experiments. While some teams tested different materials to best withstand the harsh conditions in the stratosphere, others crafted the final box and ensured that all experiments, including a video camera, were tightly connected prior to launch (aka "duct tape fixes everything"). In addition, the participants engaged in extensive ground-based investigations and hands-on experiments, including calculations of the flight route and tests of various detectors and measurement equipment.

The students planned to record climate and weather data, such as temperature, pressure and humidity, and to measure cosmic particles. With a mixture of commercial off-the-shelf detectors (e.g. active GPS tracker and Geiger counter) and self-built devices based on Arduino (e.g. environmental sensors and cosmic-ray detectors based on scintillators or pin diodes), they felt both well prepared and adequately equipped for the scientific investigations.

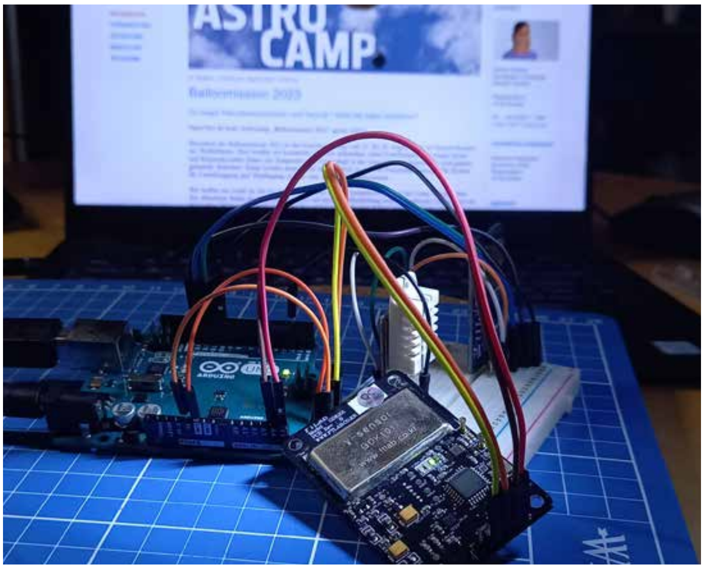


Figure 1
Preparation of the detector for gamma spectroscopy, a low-cost system based on Arduino

Figure 2
There was a lot to discuss, and spontaneous meetings were part of the young researchers' everyday work.

Figure 3
The probe, ready and waiting to take to the skies. It also featured instructions for finders on what to do with it – a small finder's fee was meant to encourage them to return the probe.

Figure 4
Group photo just before the balloon launch. Filling the balloon takes some time and is a challenging task on a very sunny day.

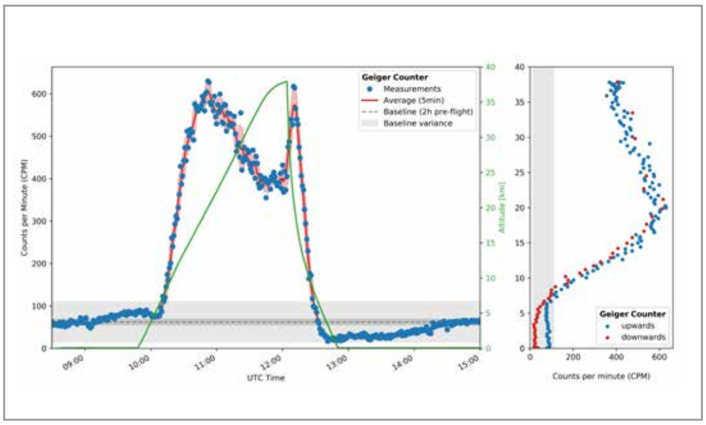


Figure 5
Plot of the cosmic-ray flight data. Results from the balloon flight measuring cosmic rays with a Geiger counter tube as a function of time (left) and altitude (right), clearly showing the shower maximum at an altitude of around 20 km.

Venturing into the stratosphere
On Wednesday morning, all measurement devices were properly placed inside the cosmic probe and the 3000 l research balloon was filled with gas. At 11:50 local time, the balloon was finally launched into the stratosphere to measure cosmic particles and climate-relevant data. The AstroCamp participants continuously tracked its flight via GPS. After an ascent of more than two hours, the balloon burst at an altitude of over 37 900 m and eventually landed about 120 km east of its starting point, near the city of Gorzów Wielkopolski in Poland.

Following the successful recovery of the balloon by the NaWi School e.V. team, the students were eager to analyse the data recorded by the different detectors. However, they quickly realised that not all the detectors had worked as expected and that even simple-sounding questions, such as "what was the maximum altitude reached during the flight?", are not that easy to answer if all the onboard GPS trackers state a different value.

The students worked in small teams to investigate their previously formulated questions and discussed their findings with their peers and mentors. They analysed the data from the Geiger counter to better understand the cosmic-ray distribution in the atmosphere and found a much higher number of cosmic rays at high altitudes than on the ground, as expected based on their pre-investigations. The variable count rates, shown in Fig. 5, can be explained by the development of air showers initiated by cosmic rays in the atmosphere. As can be seen in the figure, the maximum rate was located at an altitude of around 20 km and was passed twice during the flight – a great achievement for everyone involved in the event and a result that the students proudly presented at the International Cosmic Day in November, together with a self-made video about their AstroCamp experience.

Link to the student video on YouTube

Author contact:
Carolin Gnebner, *carolin.gnebner@desy.de*
Heike Prokoph, *heike.prokoph@cta-observatory.org*

References:

[1] https://cosmic.desy.de
[2] https://www.desy.de/astrocamp
[3] https://icd.desy.de

Investigating MGRO J1908+06: Insights from VERITAS observations

Decade of gamma-ray observations reveals potential origin of galactic PeVatron candidate

The VERITAS imaging atmospheric Cherenkov telescope in the USA has been observing the gamma-ray sky for over a decade with the participation of DESY scientists. In light of the recent discovery of sources capable of accelerating particles to very high energies, the VERITAS collaboration carried out new observations for the yet unidentified object MGRO J1908+06 and conducted a re-analysis, in which DESY scientists were strongly involved. By examining the physical properties, acceleration mechanisms and environmental interactions of pulsar wind nebulae, the research contributes to our understanding of the origins of cosmic rays.

Introduction

The origins of very-high-energy and ultrahigh-energy cosmic rays within our galaxy remain enigmatic. It has been shown that pulsar wind nebulae (PWNe) feature among galactic PeVatrons – sources capable of accelerating particles to energies surpassing the petaelectronvolt (PeV) threshold. Investigating gamma-ray emission from PWNe provides insights into the characteristics of supernova explosions and their remnants, and enhances our understanding of the physical properties and acceleration mechanisms of PWNe, as well as their environmental impact.

After a pulsar forms in a supernova explosion, its rapid rotation and intense magnetic fields generate a high-energy wind of accelerated particles. This wind can interact with the surrounding medium, giving rise to a PWN. In the early stages of their evolution, PWNe are eventually disrupted by the reverse shock of the supernova remnant. This shock can be highly asymmetrical, driven by a non-homogeneous interstellar medium, thereby leaving a deformed relic PWN as a result. Further compression or an initial kick imparted by the supernova explosion results in the separation of the relic PWN and the formation of a new PWN at the pulsar's new position. In the search for PeVatrons, ground-based gamma-ray observatories such as VERITAS emerge as crucial instruments for probing these complex GeV to TeV morphologies, thanks to their ability to resolve structure.

MGRO J1908+06 was first detected by the Milagro observatory in the USA in 2007 and has since been detected by several observatories, including VERITAS [1]. Several potential counter-parts have been suggested to explain the origin of its emission, such as a PWN or a supernova remnant. However, this origin still remains ambiguous. Furthermore, the spatial extension of MGRO J1908+06 adds layers of complexity to its study. Unlike point sources, extended sources require nuanced analysis techniques to accurately disentangle their emission from background signals.

Analysis and results

Over the past decade, the VERITAS collaboration has dedicated around 130 hours to observing MGRO J1908+06. Given that the GeV to TeV emission occupies a substantial fraction of the observatory's field of view, a specialised analysis technique is required to estimate the residual background signal. This involves the production of background models from selected archival VERITAS observations, which are then fitted to the actual observations to extract the gamma-ray signal. Source models are then fitted to the data to investigate the morphology and extract spectra.

The systematic effects of the analysis method are assessed using a mimic data method. This consists of generating sets of empty gamma-ray fields that match the actual observational conditions. These mimic data sets are then analysed in a similar way to the treatment of the observational data.

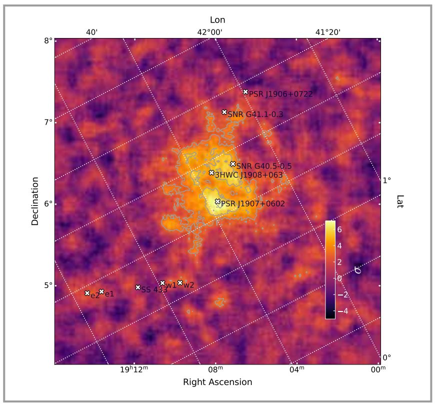


Figure 1
Significance map of the MGRO J1908+06 region. The contours indicate the significance values of 3, 5 and 7 σ. Possible associated sources are indicated with white crosses: the supernova remnants G40.5-0.5 and G41.1-0.3 and the pulsars PSR J1907+0602 and PSR J1906+0722.

Figure 1 shows the significance map resulting from the analysis. The highest significance is seen at the position of a pulsar (PSR J1907+0602) and around the source's central position. The high-energy emission appears spatially extended, and the spectral shape can be described by a power law.

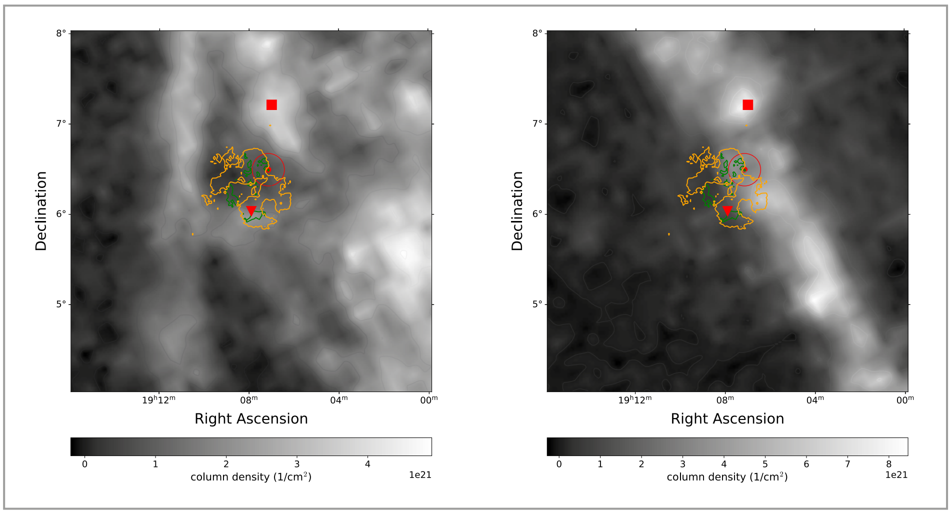


Figure 2
^{12}CO (J = 1–0) map (10–40 km/s and 40–70 km/s) overlaid with gamma-ray contours (VERITAS, 0.8–12.3 TeV). Possible counterparts are marked: PSR 1907+0602 (triangle), SNR G40.5-05 (dot circle) and Fermi-LAT PSR J1906.9+0712 (square). Data from the Smithsonian Astrophysical Observatory's 1.2 m CO survey.

An energy-dependent analysis reveals more information about the true nature of the emission. The analysis shows that the low-energy emission is concentrated towards the centre of MGRO J1908+06, whereas the high-energy emission is shifted towards the pulsar position.

A plausible explanation is that the emission stems from a leptonic origin, with the PWN potentially interacting with the host supernova remnant. Newly accelerated high-energy electrons from the PWN are observed closer to the present pulsar position, while electrons from earlier times reside within the relic PWN and have undergone cooling over the pulsar's lifetime.

This scenario finds support in an analysis of molecular clouds. Figure 2 illustrates the velocity-integrated column density in ^{12}CO, which acts as a tracer for the density of molecular gas in the region. While high densities of hadrons would suggest hadronic gamma-ray production, the observed densities and the fact that the bulk of the gamma-ray emission lies in a cavity favour a leptonic origin of the emission.

Subsequently, the source's spectrum can be well described by modelling an electron population that produces photons via synchrotron radiation and inverse Compton scattering on the cosmic microwave background radiation field. Figure 3 presents the modelled spectral energy distribution alongside flux points extracted from VERITAS data and previously published results by other instruments. Moreover, the modelled electron population responsible for the emission enables the estimation of the pulsar's age (approx. 10 000 years), its distance from Earth (approx. 2000 pc) and the magnetic field strength in the region (approx. 7 μG).

Discussion and outlook

The re-analysis suggests that the emission from MGRO J1908+06 is likely of leptonic origin. The refined analysis methodology accounts for the source's extension and updates the previously published flux measurements detailed in [1]. The proposed scenario, involving a relic and a new PWN, helps to clarify the emission mechanisms within this PeVatron candidate.

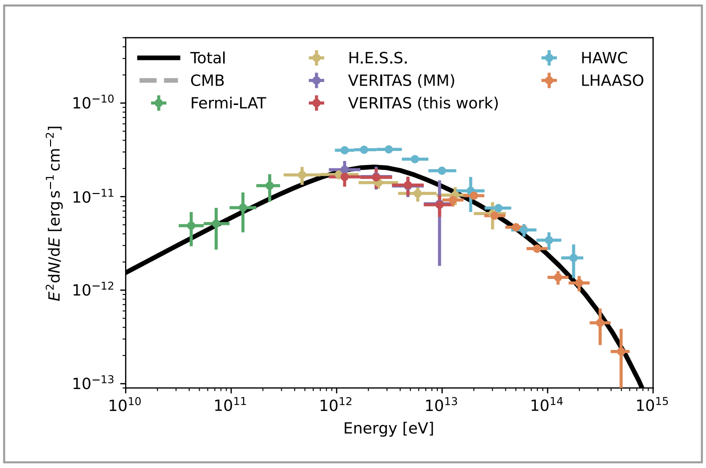


Figure 3
Spectral energy distribution of MGRO J1908+06, centred at PSR J1907+06. Flux points from Fermi-LAT, H.E.S.S., VERITAS, HAWC and LHAASO. Fit with leptonic model with inverse Compton scattering on the cosmic microwave background. Primary electron spectrum: exponential cut-off broken power law.

Although the supernova remnant G40.5-0.5 borders the emission region and may potentially contribute hadronic-based emission, its impact on the observed emission is estimated to be negligible in the analysis. However, the possible presence of additional sources in the vicinity that contribute to hadronic-based emission cannot be entirely dismissed.

Further analyses are needed to study the pulsar's proper motion and evaluate potential contributions from other sources in the field of view. The findings of this analysis are forthcoming in a joint paper involving Fermi-LAT, VERITAS and HAWC [3], providing additional insights into the object.

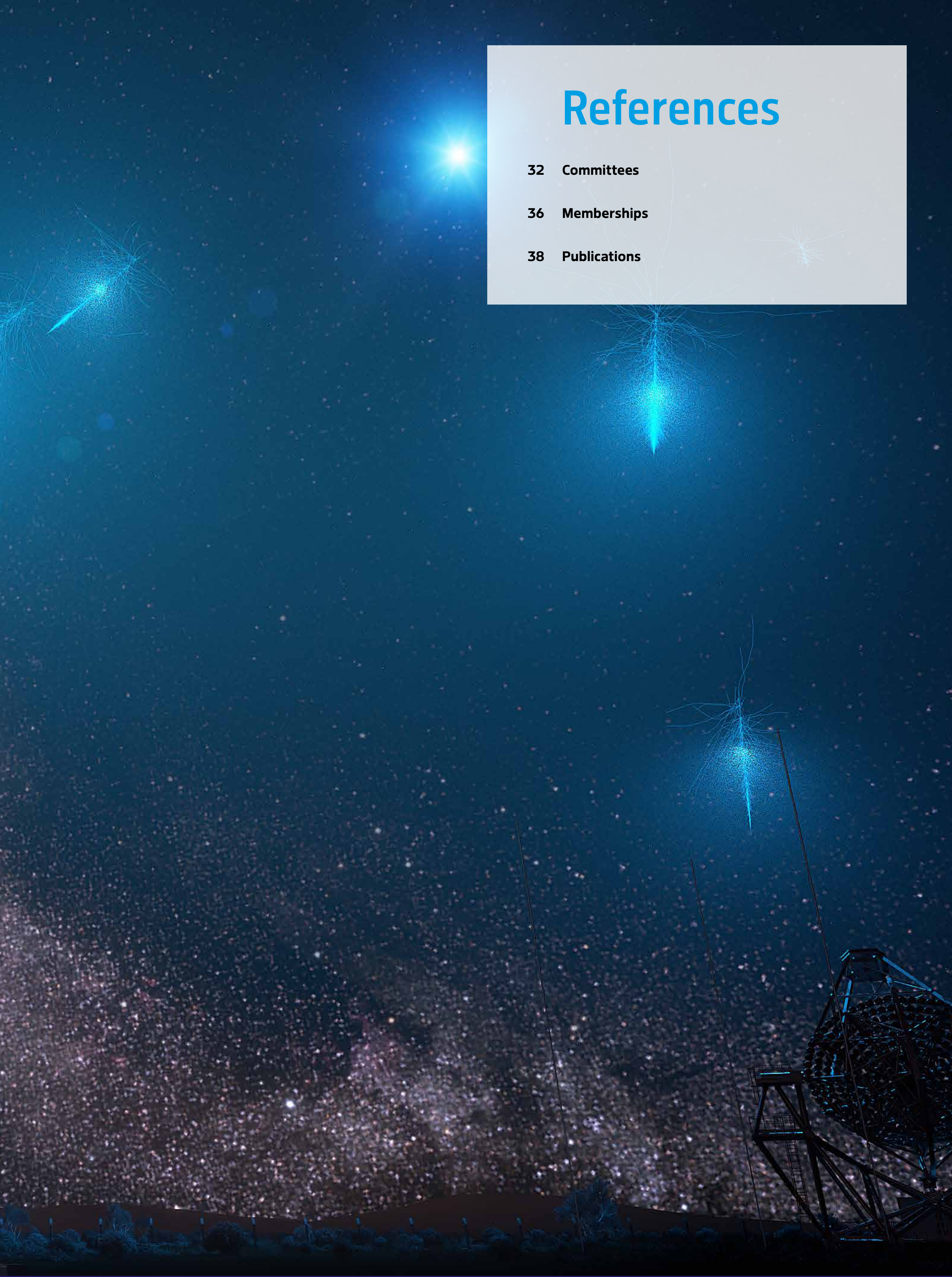
Author contact:
Tobias Kleiner, *tobias.kleiner@desy.de*

References:

[1] E. Aliu et al., Astrophys. J. 787, 166 (2014)
[2] T. Kleiner for the VERITAS Collaboration, PoS ICRC2023, 762 (2023)
[3] The VERITAS, HAWC and Fermi-LAT Collaborations, submitted to Astrophys. J., arXiv:2408.01625 (2024)

Artist's impression of very-high-energy photons from a gamma-ray burst entering Earth's atmosphere and initiating air showers that are being recorded by the H.E.S.S. telescopes

References



Committees

DESY Foundation Council

Representatives of the Federal Republic of Germany

V. Dietz (Chair)
Federal Ministry of Education and Research (BMBF)

A. Fischer
Federal Ministry of Education and Research (BMBF)

A. Höll
Federal Ministry of Economy and Climate Protection (BMWK)

Representatives of the Free and Hanseatic City of Hamburg

N. Abend
Ministry of Science, Research, Equal Opportunities and Districts

R. Greve (Deputy Chair)
Ministry of Science, Research, Equal Opportunities and Districts

Representatives of the Federal State of Brandenburg

H. Roth
Ministry of Finance and for European Affairs

S. Weber
Ministry of Science, Research and Culture

Representatives from science and industry

T. Blatt
Beiersdorf AG

M. Kraas
Olympus Surgical Technologies

B. Schwappach-Pignetaro
University Medical Center Hamburg-Eppendorf

U. Tippe
TH Wildau

Guests

R. Abela
Chair of the DESY Scientific Council

I. Gregor
Chair of the DESY Scientific Committee

C. Joithe
Chair of the DESY Works Council

D. Schirmacher-Busch (until 30 June 2023)
C. Buban (as of 1 July 2023)
DESY Equal Opportunities Officer

O. Wiestler
President of the Helmholtz Association

DESY Board of Directors

H. Dosch
Chairman of the DESY Board of Directors

C. Harringa
Administrative Division

B. Heinemann
Particle Physics Division

W. Leemans
Accelerator Division

C. Stegmann
Astroparticle Physics Division

E. Weckert
Photon Science Division

A. Willner
Chief Technology Officer

DESY Scientific Council

R. Abela (Chair)
PSI (CH)

H. Abramowicz
Tel Aviv University (IL)

W. Barletta
MIT (USA)

V. Büscher
University of Mainz (DE)

J. Hill
BNL (USA)

T. Lohse
Humboldt University of Berlin (DE)

J. Luiten
Eindhoven University of Technology (NL)

J. McEnery
NASA (USA)

B. Roldán Cuenya
Fritz Haber Institute (DE)

M. Rossbach
Ikxinta GmbH (DE)

T. Salditt
University of Göttingen (DE)

J. Schieck
Austrian Academy of Sciences (A)

C. Weinheimer
University of Münster (DE)

Guests of the Scientific Council

Chair of APC
J. Wilms
University of Erlangen-Nürnberg (DE)

Chair of MAC
M. Minty
BNL (USA)

Chair of PRC
S. Stapnes
CERN (CH)

Chair of PSC
C. David
PSI (CH)

DESY Scientific Committee
I. Gregor
DESY (DE)

European XFEL
R. Feidenhans'l
European XFEL (DE)

DESY Scientific Committee

Elected members from

FH Division:
C. Apfel (DESY/IT)
N. Davis (DESY/ATLAS)
M. Diehl (DESY/T)
R. Jacobs (DESY/FHR)
F. Januschek (DESY/ALPS, FTX)
R. Kogler (DESY/CMS)
A. Lindner (DESY/ALPS)
J. List (DESY/FTX)
I. Melzer-Pellmann (DESY/CMS)
A. Meyer (DESY/CMS)
A. Mussgiller (DESY/CMS)
F. Poblotzki (DESY/ATLAS)
S. Spannagel (DESY/ATLAS)
F. Tackmann (DESY/T)

FS Division:
K. Bagschik (DESY/FS-PETRA)
S. Bari (DESY/FS-SCS)
R. Döhrmann (DESY/FS-PETRA)
U. Frühling (DESY/FS-FLASH-O)
J. Garrevoet (DESY/FS-PETRA-S)
O. Gutowski (DESY/FS-PETRA-D)
J. Hakanpää (DESY/FS-PETRA-D)
T. Laarmann (DESY/FS-PS)
E. Plönjes-Palm (DESY/FS-FLASH-B)
O. Seeck (DESY/FS-PETRA-D)
M. Tischer (DESY/FS-US)
S. Toleikis (DESY/FS-FLASH-O)
R. Treusch (DESY/FS-FLASH-O)
A. Wefer (DESY/FS-TI)
H.-C. Wille (DESY/FS-FLASH-S)

M Division:
N. Baboi (DESY/MDI)
S. Barbanotti (DESY/MKS1)
J. Branlard (DESY/MSK)
F. Burkart (DESY/MPY1)
M. Czwalinna (DESY/MSK)
H.-J. Eckoldt (DESY/MPC)
K. Honkavaara (DESY/MPY)
G. Kube (DESY/MDI)
L. Lilje (DESY/MVS)
S. Pfeiffer (DESY/MSK)
M. Schaumann (DESY/MPY)
H. Schlarb (DESY/MSK)
M. Scholz (DESY/MXL)
S. Schreiber (DESY/MFL)
J. Schulenburg (DESY/MFL)
M. Vogt (DESY/MFL)

AP Division:
R. Bühler (DESY/Z_GA)
G. Giavitto (DESY/Z_EL)
A. Haupt (DESY/Z_DV)
A. Nelles (DESY/Z_RAD)

V Division:
L. Fimmen (DESY/ITT)
N. Hundoegger (DESY/V6)
I. Mahns (DESY/ITT)
C. Porthun (DESY/D4)
A. Simon (DESY/BAU)
D. Völker (DESY/D6)
T. Zoufal (DESY/PR)

Delegates from partner institutes and committees:
B. Atlay (HU Berlin)
F. Ellinghaus (KET)
S. Fiedler (EMBL)
C. Gutt (KfS)
J. Haller (U Hamburg)
D. Lott (Hereon)
S. Molodtsov (European XFEL)
N.N. (KfB)
K. Sengstock (U Hamburg)
K. Valerius (KAT)

Leading Scientists:
R. Aßmann (DESY/MPY)
R. Bartolini (DESY/MPY)
T. Behnke (DESY/FTX)
D. Berge (DESY/Z_GA)
F. Blekman (DESY/CMS)
K. Borras (DESY/CMS)
F. Calegari (DESY/FS-CFEL)
H. Chapman (DESY/FS-CFEL)
E. Gallo (DESY/CMS)
I. Gregor (DESY/ATLAS)
C. Grojean (DESY/T)
M. Gühr (DESY/FS-FLASH)
Ç. İşsever (DESY/ATLAS)
F. Kärtner (DESY/FS-CFEL)
M. Kowalski (DESY/Z_ICE)
J. Küpper (DESY/FS-CFEL)
A. Maier (DESY/MLS)
K. Mönig (DESY/ATLAS)
K. Peters (DESY/ATLAS)
M. Pohl (DESY/Z_THAT)
R. Porto (DESY/Z_THAT)
H. Reichert (DESY/FS-MPY)
N. Rohringer (DESY/FS-TUX)
K. Rossnagel (DESY/FS-SXQM)
S. Roth (DESY/FS-SMA)
R. Santra (DESY/CFEL)
M. Schnell-Küpper (DESY/FS-SMP)
V. Schomerus (DESY/T)
C. Schroer (DESY/FS-PETRA)
C. Schwanenberger (DESY/CMS)
G. Servant (DESY/T)
H. Sondermann (DESY/FS-CS)
A. Stierle (DESY/FS-NL)
K. Tackmann (DESY/ATLAS)
S. Techert (DESY/FS-SCS)
G. Weiglein (DESY/T)
H. Weise (DESY/MPY)
H. Yan (DESY/Z_THAT)

Physics Research Committee (PRC)

D. Charlton
University of Birmingham (UK)

B. Gavela
University of Madrid (SP)

A. Hebecker
University of Heidelberg (DE)

U. Husemann
KIT (DE)

C. Rembser
CERN (CH)

Y. Semertzidis
KAIST Seoul (KR)

S. Stapnes
CERN (CH), University of Oslo (NO)

J. Templon
NIKHEF (NL)

J. Thom-Levy
Cornell (US)

Astroparticle Physics Committee (APC)

E. Amato
INAF / University of Florence (IT)

M. Branchesi
Gran Sasso Science Institute (IT)

M. Cirelli
LPTHE/CNRS (FR)

S. Gabici
CNRS (FR)

H. Heßling
HTW Berlin (DE)

J. Holder (Vice Chair)
University of Delaware (USA)

D. Samtleben
NIKHE / Leiden University (NL)

J. Wilms (Chair)
University of Erlangen-Nürnberg (DE)

German Committee for Astroparticle Physics (KAT)

S. Funk
University of Erlangen-Nürnberg

M. Heurs
AEI

U. Katz
University of Erlangen-Nürnberg

M. Lindner
MPIK

U. Oberlack
University of Mainz

M. Roth
AIP

A. Stahl
RWTH Aachen

K. Valerius
KIT

W. Winter
DESY

Memberships

APPEC TechForum, Scientific Committee
Katharina Henjes-Kunst

ARENA Scientific Advisory Board
Anna Nelles

Astroteilchenphysik im Netzwerk Teilchenwelt
Ulrike Behrens (Chair)
Carolin Gnebner (Coordinator)

Baikal-GVD Technical Advisory Board
Marek Kowalski

Buchalter Cosmology Prize, Judging Panel
Rafael Porto

CTAO Administration and Finance Committee
David Berge

CTAO Collaboration Board
David Berge

CTAO MST Coordination Group
Markus Garczarczyk

CTAO Council
Christian Stegmann

Dahme Innovation, Steering Group
Ulrike Behrens
Christian Stegmann

ECAP Executive Board
Anna Nelles

Einstein Telescope, Observational Science Board
Rafael Porto

Einstein Telescope, Observational Science Board, Multi-Messenger Working Group
David Berge

EuCAPT Council
Walter Winter

EuCAPT Steering Committee
Andrew Taylor
Walter Winter

Haus der kleinen Forscher, Landkreis Dahme Spreewald
Adelheid Sommer (Coach)

Helmholtz Topic "Matter and Radiation from the Universe"
Christian Stegmann (Chair)

H.E.S.S. Collaboration Board
David Berge

H.E.S.S. Collaboration Steering Comittee
Christian Stegmann

H.E.S.S. DAQ Working Group
Sylvia Zhu (Coordinator)

H.E.S.S. GRB Group
Sylvia Zhu (Leader)

H.E.S.S.-IU Working Group
Dmitriy Kostunin (Coordinator)

H.E.S.S. Observation Committee
Emma de Ona Wilhelmi

H.E.S.S. Stellar Science Working Group
Emma de Ona Wilhelmi (Chair)

IceCube Collaboration, International Oversight and Finance Group
Christian Stegmann

IceCube Executive Board
Markus Ackermann
Marek Kowalski
Christian Stegmann

IceCube-Gen2 Collaboration Committee
Marek Kowalski (Chair)

IceCube-Gen2 Project Office
Markus Ackermann

Institute for the Physics of the Universe, Aix-Marseille University, Scientific and Teaching Advisory Board
Christian Stegmann

International Particle Physics Outreach Group (IPPOG), Steering Group Global Cosmics
Carolin Gnebner (Chair)

IUPAP Neutrino Panel
Marek Kowalski

Jugend forscht Berlin
Adelheid Sommer (Juror)

Jugend präsentiert
Adelheid Sommer (Juror)

Karl Heinz Beckurts Foundation
Christian Stegmann (Chair of the Board)

Komitee für Astroteilchenphysik (KAT)
David Berge
Marek Kowalski
Christian Stegmannn (Ex-officio Member)
Walter Winter

MAGIC Collaboration Board
Markus Garczarczyk (DESY Representative)

Netzwerk der Schülerlabore in der Helmholtz-Gemeinschaft
Adelheid Sommer (Chair)

NIKHEF Scientific Advisory Committee
Marek Kowalski

***Physik in unserer Zeit*, Board of Trustees**
Christian Stegmann

Potsdam Research Network PEARLS, Stifterversammlung
Ulrike Behrens (DESY Representative)

Potsdam Research Network PEARLS, Wissenschaftliches Kollegium
Martin Pohl (DESY Representative)

ProWissen Potsdam e.V., Arbeitskreis
Ulrike Behrens (Co-Chair)

ProWissen Potsdam e.V., Kuratorium
Ulrike Behrens (DESY Representative)

Rat Deutscher Sternwarten
Martin Pohl (DESY Representative)

RNO-G Executive Board
Anna Nelles

Schwarzschild–Couder Telescope, Project Board
Markus Garczarczyk (DESY Representative)

SKA High Energy Cosmic Particles Science Working Group
Anna Nelles (Chair)

TeV Particle Astronomy, International Scientific Advisory Committee
Andrew Taylor

ULTRASAT Science Board
Marek Kowalski

VERITAS Science Board
Gernot Maier (DESY Representative)

VERITAS Speaker's Bureau
Martin Pohl (Chair)

VERITAS Time Allocation Committee
Martin Pohl

ZTF Collaboration Board
Marek Kowalski

Publications

A. Acharyya et al.
Search for Ultraheavy Dark Matter from Observations of Dwarf Spheroidal Galaxies with VERITAS.
The astrophysical journal / 1,
945(2):101, and PUBDB-2022-07671,
arXiv:2302.08784.
doi: 10.3847/1538-4357/acbc7b.

A. Acharyya et al.
Sensitivity of the Cherenkov Telescope Array to TeV photon emission from the Large Magellanic Cloud.
Monthly notices of the Royal Astronomical Society, 523(4):5353, and
PUBDB-2023-06222, arXiv:2305.16707.
doi: 10.1093/mnras/stad1576.

J. A. Aguilar et al.
Triboelectric backgrounds to radio-based polar ultra-high energy neutrino (UHEN) experiments.
Astroparticle physics, 145:102790, and
PUBDB-2022-06878, arXiv:2103.06079.
doi: 10.1016/j.astropartphys.2022.102790.

J. A. Aguilar et al.
Radiofrequency ice dielectric measurements at Summit Station, Greenland.
Journal of glaciology,
xx:1, and PUBDB-2023-07076,
arXiv:2212.10285.
doi: 10.1017/jog.2023.72.

L. Aldoroty et al.
Bump Morphology of the CMAGIC Diagram.
The astrophysical journal / 1,
948(1):10, and PUBDB-2023-03168,
arXiv:2210.06708.
doi: 10.3847/1538-4357/acad78.

G. Anderson et al.
Rapid radio brightening of GRB 210702A.
Monthly notices of the Royal Astronomical Society,
523(4):4992, and PUBDB-2023-03986,
arXiv:2211.11212.
arXiv:2211.11212.
doi: 10.1093/mnras/stad1635.

Arianna Collaboration.
Developing new analysis tools for near surface radio-based neutrino detectors.
Journal of cosmology and astroparticle physics, 10:060, and PUBDB-2024-00178,
arXiv:2307.07188.
doi: 10.1088/1475-7516/2023/10/060.

O. A. L. Asin, D. Rodgers-Lee and A. Taylor.
A galactic breeze origin for the Fermi bubbles emission.
Monthly notices of the Royal Astronomical Society,
518(4):6083, and PUBDB-2023-00808,
arXiv:2207.09189.
doi: 10.1093/mnras/stac3517.

S. Ben-Ami et al.
The Large Array Survey Telescope—Science Goals.
Publications of the Astronomical Society of the Pacific, 135(1050):085002,
and PUBDB-2023-05115,
arXiv:2304.02719.
doi: 10.1088/1538-3873/aceb30.

V. D. Berlea et al.
Total Ionizing Dose effects on CMOS image sensor for the ULTRASAT space mission.
Frontier Detectors for Frontier Physics: 15th Pisa Meeting on Advanced Detectors, La Biodola - Isola d'Elba (Italy), 22 May 2022 - 28 May 2022.
Nuclear instruments & methods in physics research / A, vol. 1054:168463,
and PUBDB-2023-03813,
arXiv:2306.15307.
North-Holland Publ. Co., Amsterdam.
doi: 10.1016/j.nima.2023.168463.

L. Blanchet et al.
Gravitational Wave Flux and Quadrupole Modes from Quasi-Circular Non-Spinning Compact Binaries to the Fourth Post-Newtonian Order.
Physical review / D, 108(6):064041,
and PUBDB-2023-05916,
DESY-23-044. arXiv:2304.11186.
doi: 10.1103/PhysRevD.108.064041.

L. Blanchet et al.
Gravitational-Wave Phasing of Compact Binary Systems to the Fourth-and-a-Half post-Newtonian Order.
Physical review letters, 131(12):121402,
and PUBDB-2023-05912,
DESY-23-043. arXiv:2304.11185.
doi: 10.1103/PhysRevLett.131.121402.

F. Bradascio et al.
The NectarCAM timing system.
Nuclear instruments & methods in physics research / A, 1054:168398,
and PUBDB-2023-04000,
arXiv:2301.13828.
doi: 10.1016/j.nima.2023.168398.

N. Bucciantini et al.
Simultaneous space and phase resolved X-ray polarimetry of the Crab pulsar and nebula.
Nature astronomy, 7:602,
and PUBDB-2022-03778,
arXiv:2207.05573.
doi: 10.1038/s41550-023-01936-8.

Consortium, Cherenkov Telescope Array.
Sensitivity of the Cherenkov Telescope Array to spectral signatures of hadronic PeVatrons with application to Galactic Supernova Remnants.
Astroparticle physics, 150:102850,
and PUBDB-2023-04419,
arXiv:2303.15007.
doi: 10.1016/j.astropartphys.2023.102850.

A. Corstanje et al.
A high-precision interpolation method for pulsed radio signals from cosmic-ray air showers.
Journal of Instrumentation, 18(09):P09005, and PUBDB-2023-06220, arXiv:2306.13514.
doi: 10.1088/1748-0221/18/09/P09005.

M. W. Coughlin et al.
A Data Science Platform to Enable Time-domain Astronomy.
The astrophysical journal / Supplement series, 267(2):31, and PUBDB-2023-04851, arXiv:2305.00108.
doi: 10.3847/1538-4365/acdee1.

CTA-LST Collaboration.
Observations of the Crab Nebula and Pulsar with the Largesized Telescope Prototype of the Cherenkov Telescope Array.
The astrophysical journal / Part 1, 956(2):80, and PUBDB-2024-00184, arXiv:2306.12960.
doi: 10.3847/1538-4357/ace89d.

F. Dachs et al.
Development of a large-area, light-weight module using the MALTA monolithic pixel detector.
Nuclear instruments & methods in physics research / A, 1047:167809, and PUBDB-2023-00437.
doi: 10.1016/j.nima.2022.167809.

E. A. Dijck et al.
Sympathetically cooled highly charged ions in a radio-frequency trap with superconducting magnetic shielding.
Review of scientific instruments, 94(8):083203, and PUBDB-2023-06216, arXiv:2306.01670.
doi: 10.1063/5.0160537.

C. Dlapa, J. M. Henn and F. J. Wagner.
An algorithmic approach to finding canonical differential equations for elliptic Feynman integrals.
Journal of high energy physics, 08(8):120, and PUBDB-2023-05155, DESY-22-189. MPP-2022-138. TUM-HEP-1427/22. arXiv:2211.16357.
doi: 10.1007/JHEP08(2023)120.

C. Dlapa et al.
Bootstrapping the relativistic two-body problem.
Journal of high energy physics, 08(8):109, and PUBDB-2023-06214, arXiv:2304.01275. DESY-23-041.
doi: 10.1007/JHEP08(2023)109.

C. Dlapa et al.
Radiation Reaction and Gravitational Waves at Fourth Post-Minkowskian Order.
Physical review letters, 130(10):101401, and PUBDB-2023-07801, arXiv:2210.05541. DESY-22-158.
doi: 10.1103/PhysRevLett.130.101401.

D. Dobrijević et al.
Future developments of radiation tolerant sensors based on the MALTA architecture.
Journal of Instrumentation, 18(03):C03013, and PUBDB-2023-06884.
doi: 10.1088/1748-0221/18/03/C03013.

T. Dorigo et al.
Toward the end-to-end optimization of particle physics instruments with differentiable programming.
Reviews in physics, 10:100085, and PUBDB-2023-08009, arXiv:2203.13818.
doi: 10.1016/j.revip.2023.100085.

L. Fasselt et al.
Energy calibration through X-ray absorption of the DECALsensor, a monolithic active pixel sensor prototype for digital electromagnetic calorimetry and tracking.
Frontiers in physics, 11:1231336, and PUBDB-2023-03117.
doi: 10.3389/fphy.2023.1231336.

D. Fiorillo et al.
Searches for dark matter decay with ultra-high-energy neutrinos endure backgrounds.
Physical review / D, 108(10):103012, and PUBDB-2023-03923, arXiv:2307.02538.
doi: 10.1103/PhysRevD.108.103012.

L. Fischer, R. Naab and A. Trettin.
Treating detector systematics via a likelihood free inference method.
Journal of Instrumentation, 18(10):P10019, and PUBDB-2023-01830, arXiv:2305.02257.
doi: 10.1088/1748-0221/18/10/P10019.

K. Fulat et al.
Kinetic Simulations of Nonrelativistic High-mach-number Perpendicular Shocks Propagating in a Turbulent Medium.
The astrophysical journal / Part 1, 959(2):119, and PUBDB-2023-08053, arXiv:2310.14388.
doi: 10.3847/1538-4357/ad04dc.

Gammapy Collaboration.
Gammapy: A Python package for gamma-ray astronomy.
Astronomy and astrophysics, 678:A157, and PUBDB-2023-06340, arXiv:2308.13584.
doi: 10.1051/0004-6361/202346488.

G. Gustavino et al.
Timing performance of radiation hard MALTA monolithic pixel sensors.
Journal of Instrumentation, 18(03):C03011, and PUBDB-2023-06895, arXiv:2209.14676.
doi: 10.1088/1748-0221/18/03/C03011.

S. Ohm and S. Wagner.
Current status and operation of the H.E.S.S. array of imaging atmospheric Cherenkov telescopes.
XI International Workshop on Ring Imaging Cherenkov Detectors, Edinburgh (UK), 12 Sep 2022 - 16 Sep 2022.
Nuclear instruments & methods in physics research / A, vol. 1055:168442, and PUBDB-2023-03740, arXiv:2306.02716. North-Holland Publ. Co., Amsterdam.
doi: 10.1016/j.nima.2023.168442.

H. E. S. S. Collaboration.
Detection of extended gamma-ray emission around the Geminga pulsar with H.E.S.S.
Astronomy and astrophysics, 673:A148, and PUBDB-2023-507063, arXiv:2304.02631.
doi: 10.1051/0004-6361/202245776.

H. E. S. S. Collaboration.
Discovery of a Radiation Component from the Vela Pulsar Reaching 20 Teraelectronvolts.
Nature astronomy, 7(11):1341, and PUBDB-2023-06202, arXiv:2310.06181.
doi: 10.1038/s41550-023-02052-3.

H. E. S. S. Collaboration.
HESS J1809−193: A halo of escaped electrons around a pulsarwind nebula?
Astronomy and astrophysics, 672:A103, and PUBDB-2023-03579, arXiv:2302.13663.
doi: 10.1051/0004-6361/202245459.

H. E. S. S. Collaboration.
Search for the evaporation of primordial black holes with H.E.S.S.
Journal of cosmology and astroparticle physics, 04(04):040, and PUBDB-2023-04843, arXiv:2303.12855.
doi: 10.1088/1475-7516/2023/04/040.

H. E. S. S. Collaboration.
The Vanishing of the Primary Emission Region in PKS 1510–089.
The astrophysical journal / 2, 952(2):L38, and PUBDB-2023-05117, arXiv:2307.01692.
doi: 10.3847/2041-8213/ace3c0.

H. E. S. S. Collaboration and Fermi-LAT Collaboration and S, H. E. S.
Constraints on the Intergalactic Magnetic Field Using Fermi-LAT and H.E.S.S. Blazar Observations.
The astrophysical journal / 2, 950(2):L16, and PUBDB-2023-03994, arXiv:2306.05132.
doi: 10.3847/2041-8213/acd777.

L. Harvey et al.
Early-time spectroscopic modelling of the transitional Type Ia Supernova 2021rhu with TARDIS.
Monthly notices of the Royal Astronomical Society, 522(3):4444, and PUBDB-2023-03170, arXiv:2304.10129.
doi: 10.1093/mnras/stad1226.

Q. Henry and F. Larrouturou.
Conservative tail and failed-tail effects at the fifth post-Newtonian order.
Physical review / D, 108(8):084048, and PUBDB-2023-07190, arXiv:2307.05860. DESY-23-100.
doi: 10.1103/PhysRevD.108.084048.

Q. Henry, F. Larrouturou and C. Le Poncin-Lafitte.
Electromagnetic fields in compact binaries: a post-Newtonian approach.
Physical review / D, 108(2):024020, and PUBDB-2023-04128, DESY-23-008. arXiv:2303.17536.
doi: 10.1103/PhysRevD.108.024020.

H. E. S. S. Collaboration.
Constraining the cosmic-ray pressure in the inner Virgo Cluster using H.E.S.S. observations of M 87.
Astronomy and astrophysics, 675:A138, and PUBDB-2023-04110, arXiv:2305.09607.
doi: 10.1051/0004-6361/202346056.

IceCube Collaboration.
A Search for Coincident Neutrino Emission from Fast Radio Bursts with Seven Years of IceCube Cascade Events.
The astrophysical journal / 1, 946(2):80, and PUBDB-2023-02099, arXiv:2212.06702.
doi: 10.3847/1538-4357/acbea0.

IceCube Collaboration.
A Search for IceCube Sub-TeV Neutrinos Correlated with Gravitational-wave Events Detected By LIGO/Virgo.
The astrophysical journal / Part 1, 959(2):96, and PUBDB-2024-00171, arXiv:2303.15970.
doi: 10.3847/1538-4357/aceefc.

IceCube Collaboration.
Constraining High-energy Neutrino Emission from Supernovae with IceCube.
The astrophysical journal / 2, 949(1):L12, and PUBDB-2023-03726, arXiv:2303.03316.
doi: 10.3847/2041-8213/acd2c9.

IceCube Collaboration.
Constraints on Populations of Neutrino Sources from Searches in the Directions of IceCube Neutrino Alerts.
The astrophysical journal / 1, 951(1):45,
and PUBDB-2023-04063,
arXiv:2210.04930.
doi: 10.3847/1538-4357/acd2ca.

IceCube Collaboration.
D-Egg: a dual PMT optical module for IceCube.
Journal of Instrumentation, 18(04):P04014,
and PUBDB-2023-03038,
arXiv:2212.14526.
doi: 10.1088/1748-0221/18/04/P04014.

IceCube Collaboration.
IceCat-1: The IceCube Event Catalog of Alert Tracks.
The astrophysical journal / Supplement series, 269(1):25,
and PUBDB-2024-00180,
arXiv:2304.01174.
doi: 10.3847/1538-4365/acfa95.

IceCube Collaboration.
IceCube Search for Neutrinos Coincident with Gravitational Wave Events from LIGO/Virgo Run O3.
The astrophysical journal / 1, 944(1):80,
and PUBDB-2023-03040,
arXiv:2208.09532.
doi: 10.3847/1538-4357/aca5fc.

IceCube Collaboration.
Limits on Neutrino Emission from GRB 221009A from MeV to PeV Using the IceCube Neutrino Observatory.
The astrophysical journal / 2, 946(1):L26,
and PUBDB-2023-02988,
arXiv:2302.05459.
doi: 10.3847/2041-8213/acc077.

IceCube Collaboration.
Measurement of atmospheric neutrino mixing with improved IceCube DeepCore calibration and data processing.
Physical review / D, 108(1):012014,
and PUBDB-2023-04849,
arXiv:2304.12236.
doi: 10.1103/PhysRevD.108.012014.

IceCube Collaboration.
Observation of high-energy neutrinos from the Galactic plane.
Science / Science now,
380(6652):1338,
and PUBDB-2023-04853,
arXiv:2307.04427.
doi: 10.1126/science.adc9818.

IceCube Collaboration.
Observation of seasonal variations of the flux of high-energy atmospheric neutrinos with IceCube.
The European physical journal / C,
83(9):777, and PUBDB-2023-06151,
arXiv:2303.04682.
doi: 10.1140/epjc/s10052-023-11679-5.

IceCube Collaboration.
Search for Correlations of High-energy Neutrinos Detected in IceCube with Radio-bright AGN and Gamma-Ray Emission from Blazars.
The astrophysical journal / Part 1,
954(1):75, and PUBDB-2023-05489,
arXiv:2304.12675.
doi: 10.3847/1538-4357/acdfcb.

IceCube Collaboration.
Search for Extended Sources of Neutrino Emission in the Galactic Plane with IceCube.
The astrophysical journal / Part 1,
956(1):20, and PUBDB-2023-06215,
arXiv:2307.07576.
doi: 10.3847/1538-4357/acf713.

IceCube Collaboration.
Search for sub-TeV Neutrino Emission from Novae with IceCube-DeepCore.
The astrophysical journal / Part 1,
953(2):160, and PUBDB-2023-06273,
arXiv:2212.06810.
doi: 10.3847/1538-4357/acdc1b.

IceCube Collaboration.
Searches for connections between dark matter and high-energy neutrinos with IceCube.
Journal of cosmology and astroparticle physics, 10(10):003,
and PUBDB-2024-00170,
arXiv:2205.12950.
doi: 10.1088/1475-7516/2023/10/003.

IceCube Collaboration.
Searches for Neutrinos from Large High Altitude Air Shower Observatory Ultra-high-energy γ-Ray Sources Using the IceCube Neutrino Observatory.
The astrophysical journal / 2, 945(1):L8,
and PUBDB-2023-03128,
arXiv:2211.14184.
doi: 10.3847/2041-8213/acb933.

A. Jaitly, D. Kostiunin and K. Cescon.
Searching for Short Timescale Transients in Gamma-ray Telescope Data.
Galaxies, 11(4):88,
and PUBDB-2023-03918.
doi: 10.3390/galaxies11040088.

R. Jinno et al.
Machine learning Post-Minkowskian integrals.
Journal of high energy physics, 07(7):181,
and PUBDB-2023-04582,
arXiv:2209.01091. IFT-UAM/CSIC-22-97.
DESY-22-144. TUM-HEP 1392/22.
doi: 10.1007/JHEP07(2023)181.

G. Kälin, J. Neef and R. A. Porto.
Radiation-reaction in the Effective Field Theory approach to Post-Minkowskian dynamics.
Journal of high energy physics, 01(1):140, and PUBDB-2023-01183, arXiv:2207.00580. DESY-22-109.
doi: 10.1007/JHEP01(2023)140.

D. Khangulyan, F. Aharonian and A. M. Taylor.
On the Properties of Inverse Compton Spectra Generated by Upscattering a Power-law Distribution of Target Photons.
The astrophysical journal / Part 1, 954(2):186, and PUBDB-2023-06886, arXiv:2307.12467.
doi: 10.3847/1538-4357/acea5d.

D. Khangulyan, A. M. Taylor and F. Aharonian.
The Formation of Hard Very High Energy Spectra from Gamma-ray Burst Afterglows via Two-zone Synchrotron Self-Compton Emission.
The astrophysical journal / Part 1, 947(2):87, and PUBDB-2023-07081, arXiv:2301.08578.
doi: 10.3847/1538-4357/acc24e.

M. Klinger et al.
Probing the multiwavelength emission scenario of GRB 190114C.
Monthly notices of the Royal Astronomical Society, 520(1):839, and PUBDB-2023-00666, arXiv:2206.11148.
doi: 10.1093/mnras/stad142.

M. Klinger et al.
The Multiwavelength Picture of GRB 221009A's Afterglow.
Monthly notices of the Royal Astronomical Society / Letters, 529(1):L47, and PUBDB-2023-04882, arXiv:2308.13854.
doi: 10.1093/mnrasl/slad185.

T. M. Kraetzschmar et al.
Generalised Known Kinematics (GKK): an approach for kinematic observables in pair production events with decays involving invisible particles.
Journal of high energy physics, 07(7):101, and PUBDB-2023-07865, arXiv:2109.14455. MPP-2021-137.
doi: 10.1007/JHEP07(2023)101.

A. Kushwaha, S. Malik and S. Shankaranarayanan.
Fast radio bursts signal high-frequency gravitational waves.
International journal of modern physics, 32(14):2342010, and PUBDB-2023-06890, arXiv:2311.11150.
doi: 10.1142/s0218271823420105.

F. Larrouturou, L. Blanchet and L. Heisenberg.
Absence of gravitational polarization mechanism in the canonical bimetric theory.
Physical review / D, 107:124021, and PUBDB-2023-03735, DESY-23-010. arXiv:2302.02690.
doi: 10.1103/PhysRevD.107.124021.

A. K. Leibovich, B. A. Pardo and Z. Yang.
Radiation reaction for nonspinning bodies at 4.5PN in the effective field theory approach.
Physical review / D, 108(2):024017, and PUBDB-2024-00116, arXiv:2302.11016. DESY-23-218.
doi: 10.1103/PhysRevD.108.024017.

MAGIC Collaboration.
A lower bound on intergalactic magnetic fields from time variability of 1ES 0229+200 from MAGIC and Fermi/LAT observations.
Astronomy and astrophysics, 670:A145, and PUBDB-2023-02101, arXiv:2210.03321.
doi: 10.1051/0004-6361/202244126.

MAGIC Collaboration.
Long-term multi-wavelength study of 1ES 0647+250.
Astronomy and astrophysics, 670:A49, and PUBDB-2023-07088, arXiv:2211.13268.
doi: 10.1051/0004-6361/202244477.

MAGIC Collaboration.
MAGIC observations provide compelling evidence of hadronic multi-TeV emission from the putative PeVatron SNR G106.3+2.7.
Astronomy and astrophysics, 671:A12, and PUBDB-2023-03148, arXiv:2211.15321.
doi: 10.1051/0004-6361/202244931.

MAGIC Collaboration.
Multimessenger Characterization of Markarian 501 during Historically Low X-Ray and γ-Ray Activity.
The astrophysical journal / Supplement series, 266(2):37, and PUBDB-2023-04068, arXiv:2210.02547.
doi: 10.3847/1538-4365/acc181.

MAGIC Collaboration.
Search for Gamma-Ray Spectral Lines from Dark Matter Annihilation up to 100 TeV toward the Galactic Center with MAGIC.
Physical review letters, 130(6):061002, and PUBDB-2023-05032, arXiv:2212.10527. KEK-TH-2487. KEK-Cosmo-0307.
doi: 10.1103/PhysRevLett.130.061002.

MAGIC Collaboration.
Study of the GeV to TeV morphology of the γ Cygni SNR (G78.2+2.1) with MAGIC and Fermi-LAT – Evidence for cosmic ray escape.
Astronomy and astrophysics, 670:A8, and PUBDB-2023-01336, arXiv:2010.15854.
doi: 10.1051/0004-6361/202038748.

K. Maguire et al.
SN 2020udy: a SN Iax with strict limits on interaction consistent with a helium-star companion.
Monthly notices of the Royal Astronomical Society, 525(1):1210, and PUBDB-2023-07080, arXiv:2304.12361.
doi: 10.1093/mnras/stad2316.

S. Malik, K. H. Yuen and H. Yan.
Correction to: Diagnosis of 3D magnetic field and mode composition in MHD turbulence with Y-parameter.
Monthly notices of the Royal Astronomical Society, 526(4):6258, and PUBDB-2024-00197, arXiv:2303.17282.
doi: 10.1093/mnras/stad3160.

S. Malik, K. H. Yuen and H. Yan.
Diagnosis of 3D magnetic field and mode composition in MHD turbulence with Y-parameter.
Monthly notices of the Royal Astronomical Society, 524(4):6102, and PUBDB-2023-04675, arXiv:2303.17282.
doi: 10.1093/mnras/stad2225.

D. Meyer et al.
Mixing of materials in magnetized core-collapse supernova remnants.
Monthly notices of the Royal Astronomical Society, 521(4):5354, and PUBDB-2023-06529, arXiv:2303.12579.
doi: 10.1093/mnras/stad906.

D. Meyer et al.
On the plerionic rectangular supernova remnants of static progenitors.
Monthly notices of the Royal Astronomical Society, 527(3):5514, and PUBDB-2023-08051, arXiv:2311.06817.
doi: 10.1093/mnras/stad3495.

P. Mitra et al.
Reconstructing air shower parameters with MGMR3D.
Physical review / D, 108(8):083041, and PUBDB-2024-00169, arXiv:2307.04242.
doi: 10.1103/PhysRevD.108.083041.

P. Morris et al.
Pre-acceleration in the Electron Foreshock II : Oblique Whistler Waves.
The astrophysical journal / 1, 944(1):13, and PUBDB-2022-05114, arXiv:2301.00872.
doi: 10.3847/1538-4357/acaec8.

V. Nedora et al.
Modelling kilonova afterglows: Effects of the thermal electron population and interaction with GRB outflows.
Monthly notices of the Royal Astronomical Society, 520(2):2727, and PUBDB-2023-06530, arXiv:2208.01558.
doi: 10.1093/mnras/stad175.

L. Nozka et al.
Upgraded Cherenkov time-of-flight detector for the AFP project.
Optics express, 31(3):3998, and PUBDB-2023-07260.
doi: 10.1364/OE.480624.

E. O. Ofek et al.
The Large Array Survey Telescope—System Overview and Performances.
Publications of the Astronomical Society of the Pacific, 135(1048):065001, and PUBDB-2023-06892.
doi: 10.1088/1538-3873/acd8f0.

E. M. de Ona Wilhelmi, R. López-Coto and Y. Su.
High energy gamma-ray emission powered by a young protostar: the case of S255 NIRS 3.
Monthly notices of the Royal Astronomical Society, 523(1):105, and PUBDB-2023-01526, arXiv:2305.04571.
doi: 10.1093/mnras/stad1413.

P. D. Pavaskar, H. Yan and J. Cho.
Magnetic field measurement from the Davis-Chandrasekhar-Fermi method employed with Atomic Alignment.
Monthly notices of the Royal Astronomical Society, 523:1056, and PUBDB-2023-01945, arXiv:2304.10665.
doi: 10.1093/mnras/stad1237.

H. Pernegger et al.
MALTA-Cz: a radiation hard full-size monolithic CMOS sensor with small electrodes on high-resistivity Czochralski substrate.
Journal of Instrumentation, 18(09):P09018, and PUBDB-2023-06217, arXiv:2301.03912.
doi: 10.1088/1748-0221/18/09/P09018.

I. Plaisier, S. Bouma and A. Nelles.
Reconstructing the arrival direction of neutrinos in deep in-ice radio detectors.
The European physical journal / C, 83(5):443, and PUBDB-2023-00439, arXiv:2302.00054.
doi: 10.1140/epjc/s10052-023-11604-w.

L. Pyras et al.
Atmospheric muons at PeV energies in radio neutrino detectors.
Journal of cosmology and astroparticle physics, 10:043, and PUBDB-2023-03833, arXiv:2307.04736.
doi: 10.1088/1475-7516/2023/10/043.

S. K. Rao et al.
Analog signal processing for large area SiPM in Cherenkov telescope camera.
Nuclear instruments & methods in physics research / A, 1051:168191, and PUBDB-2023-01319.
doi: 10.1016/j.nima.2023.168191.

J. C. Raymond et al.
Electron-Ion Temperature Ratio in Astrophysical Shocks.
*The astrophysical journal / Part 1, 949(2):50, and PUBDB-*2023-06532, arXiv:2303.08849.
doi: 10.3847/1538-4357/acc528.

M. van Rijnbach et al.
Performance of the MALTA telescope.
The European physical journal / C, 83(7):581, and PUBDB-2023-04416, arXiv:2304.01104.
doi: 10.1140/epjc/s10052-023-11760-z.

RNO-G Collaboration.
Erratum: Design and sensitivity of the Radio Neutrino Observatory in Greenland (RNO-G).
Journal of Instrumentation, 18(03):E03001, and PUBDB-2024-00189, arXiv:2010.12279.
doi: 10.1088/1748-0221/18/03/E03001.

D. Rodgers-Lee et al.
The energetic particle environment of a GJ 436 b-like planet.
Monthly notices of the Royal Astronomical Society, 521(4):5880, and PUBDB-2024-00175, arXiv:2303.07058.
doi: 10.1093/mnras/stad900.

A. Roy et al.
Study of Variability in Long-term Multiwavelength Optical Lightcurves of Blazar AO 0235+164.
The astrophysical journal / Supplement series, 265(1):14, and PUBDB-2023-06893, arXiv:2301.01944.
doi: 10.3847/1538-4365/acb059.

A. Rudolph et al.
Multi-messenger Model for the Prompt Emission from GRB 221009A.
The astrophysical journal / 2, 944(2):L34, and PUBDB-2022-07144, arXiv:2212.00766. arXiv:2212.00766.
doi: 10.3847/2041-8213/acb6d7.

C. Solans Sánchez et al.
MALTA monolithic pixel sensors in TowerJazz 180 nm technology.
Nuclear instruments & methods in physics research / Section A, 1057:168787, and PUBDB-2023-06455.
doi: 10.1016/j.nima.2023.168787.

C. Spiering.
Cherenkov detectors in astroparticle physics.
Nuclear instruments & methods in physics research / Section A, 1056:168573, and PUBDB-2024-00182, arXiv:2304.02340.
doi: 10.1016/j.nima.2023.168573.

R. Stein et al.
Neutrino follow-up with the Zwicky Transient Facility: Results from the first 24 campaigns.
Monthly notices of the Royal Astronomical Society, 521(4):5046, and PUBDB-2023-06887, arXiv:2203.17135.
doi: 10.1093/mnras/stad767.

D. Tak et al.
Temporal and Spectral Evolution of Gamma-Ray Burst Broad Pulses: Identification of High-latitude Emission in the Prompt Emission.
The astrophysical journal / Part 1, 949(2):110, and PUBDB-2023-07261, arXiv:2212.07095.
doi: 10.3847/1538-4357/acc581.

A. M. Taylor, J. H. Matthews and A. R. Bell.
UHECR echoes from the Council of Giants.
Monthly notices of the Royal Astronomical Society, 524(1):631, and PUBDB-2023-04847, arXiv:2302.06489.
doi: 10.1093/mnras/stad1716.

The HESS collaboration.
H.E.S.S. Follow-up Observations of GRB 221009A.
The astrophysical journal / 2, 946(1):L27, and PUBDB-2023-01480, arXiv:2303.10558.
doi: 10.3847/2041-8213/acc405.

L. Tibaldo et al.
The future of meetings: taking stock in the particle astrophysics community.
Nature astronomy, 7(12):1408, and PUBDB-2023-06224.
doi: 10.1038/s41550-023-02152-0.

D. Trestini, F. Larrouturou and L. Blanchet.
The Quadrupole Moment of Compact Binaries to the Fourth post-Newtonian Order: Relating the Harmonic and Radiative Metrics.
Classical and quantum gravity, 40(5):055006, and PUBDB-2023-00630, DESY-22-116. arXiv:2209.02719.
doi: 10.1088/1361-6382/acb5de.

VERITAS Collaboration.
A VERITAS/Breakthrough Listen Search for Optical Technosignatures.
The astronomical journal, 166(3):84, and PUBDB-2023-07091, arXiv:2306.17680.
doi: 10.3847/1538-3881/ace347.

VERITAS Collaboration.
VERITAS and Fermi-LAT Constraints on the Gamma-Ray Emission from Superluminous Supernovae SN2015bn and SN2017egm.
The astrophysical journal / 1, 945(1):30, and PUBDB-2023-01300, arXiv:2302.06686.
doi: 10.3847/1538-4357/acb7e6.

VERITAS Collaboration.
VERITAS Discovery of Very High Energy Gamma-Ray Emission from S3 1227+25 and Multiwavelength Observations.
The astrophysical journal / 1, 950(2):152, and PUBDB-2023-03993, arXiv:2305.02860.
doi: 10.3847/1538-4357/acd2d0.

VERITAS Collaboration and H.E.S.S. Collaboration.
Multiwavelength Observations of the Blazar PKS 0735+178 in Spatial and Temporal Coincidence with an Astrophysical Neutrino Candidate IceCube-211208A.
The astrophysical journal / Part 1, 954(1):70, and PUBDB-2023-06223, arXiv:2306.17819.
doi: 10.3847/1538-4357/ace327.

N. Werner et al.
Science with a small two-band UV-photometry mission I: Mission description and follow-up observations of stellar transients.
Space science reviews, 220(1):11, and PUBDB-2024-00736, arXiv:2306.15080.
doi: 10.1007/s11214-024-01048-3.

W. Winter and C. Lunardini.
Interpretation of the neutrino emission from Tidal Disruption Events.
The astrophysical journal / 1, 948(1):42, and PUBDB-2022-02516, arXiv:2205.11538.
doi: 10.3847/1538-4357/acbe9e.

R.-z. Yang et al.
Effective Shielding of ≲10 GeV Cosmic Rays from Dense-Molecular Clumps.
Nature astronomy, 7(3):351, and PUBDB-2022-02582, arXiv:2301.06716.
doi: 10.1038/s41550-022-01868-9.

C. Yuan and W. Winter.
Electromagnetic Cascade Emission from Neutrino-Coincident Tidal Disruption Events.
The astrophysical journal / Part 1, 956:30, and PUBDB-2023-03852.
doi: 10.3847/1538-4357/acf615.

B. T. Zhang et al.
External Inverse-compton and Proton Synchrotron Emission from the Reverse Shock as the Origin of VHE Gamma Rays from the Hyper-bright GRB 221009A.
The astrophysical journal / 2, 947(1):L14, and PUBDB-2023-03075, arXiv:2211.05754. YITP-23-02.
doi: 10.3847/2041-8213/acc79f

Imprint

Publishing and contact:
Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

Hamburg location:
Notkestr. 85, 22607 Hamburg, Germany
Tel.: +49 40 8998-0, Fax: +49 40 8998-3282
desyinfo@desy.de

Zeuthen location:
Platanenallee 6, 15738 Zeuthen, Germany
Tel.: +49 33762 7-70, Fax: +49 33762 7-7413
desyinfo-zeuthen@desy.de

www.desy.de

ISBN 978-3-945931-53-0
DOI 10.3204/PUBDB-2024-06434

Online version:
https://www.desy.de/about_desy/annual_reports/

Realisation:
Wiebke Schubotz, Kay Fürstenberg, Ilka Flegel

Editing:
Ilka Flegel, Wiebke Schubotz

Layout:
Kay Fürstenberg

Printing: Tastomat GmbH

Copy deadline: October 2024

Editorial note:
The authors of the individual articles published in this report are fully responsible for the contents.

Photographs and graphics:

DESY, Science Communication Lab
IceCube Collaboration
DESY, Gesine Born
DESY, Simeon Reusch
DESY, Susann Niedworok
IceCube Collaboration
DPG, Jürgen Lösel
DESY, Susann Niedworok
Jugend forscht
DESY, Science Communication Lab
DESY, Ulrike Behrens
proWissen Potsdam e.V.
DESY, Science Communication Lab
Kayla Leonard

Pozzi Lorenzo and Liceo Respighi
DESY, Ashley Jones
NANOGrav/Sonoma State University/
Aurore Simonnet
Science Copyright © 2024 the authors, some
rights reserved; exclusive licensee American
Association for the Advancement of Science
H.E.S.S. Collaboration
Adam Block/Mount Lemmon SkyCenter/
University of Arizona, CC BY-SA 4.0
NASA, ESA, S. Baum and C. O'Dea (RIT),
R. Perley and W. Cotton (NRAO/AUI/NSF),
and the Hubble Heritage Team (STScI/AURA)
DESY, Marc Klinger, CC-BY 4

DESY, Heike Prokoph
DESY, Carolin Gnebner
DESY, Ulrike Behrens
DESY/H.E.S.S. Collaboration, 2023
NASA, ESA, S. Baum and C. O'Dea (RIT),
R. Perley and W. Cotton (NRAO/AUI/NSF),
and the Hubble Heritage Team (STScI/
AURA)
DESY, Science Communication Lab
IceCube Collaboration

The figures were reproduced by permission of authors or journals.

Acknowledgement:
We would like to thank all authors and everyone who helped in the creation of this annual report.

Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

Helmholtz contributes to solving major challenges facing society, science and the economy through top-level scientific achievements in six research fields: Energy, Earth and Environment, Health, Information, Matter as well as Aeronautics, Space and Transport. With about 45 000 employees at 18 research centres and an annual budget of more than 5 billion euros, Helmholtz is Germany's largest scientific organisation. Its work is rooted in the tradition of the great natural scientist Hermann von Helmholtz (1821–1894).

HELMHOLTZ

www.helmholtz.de