PROCEEDINGS OF SCIENCE

The International Workshop on Sustainable HEP

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The "Workshop on Sustainable High Energy Physics" was first held in 2021 as an international initiative to promote sustainability awareness within the physics community. This workshop series has been organised by early and mid-career researchers and conducted as a virtual three-day event in the years 2021, 2022, and 2024. This proceeding will highlight key take-away points from the third edition of the workshop held in 2024 (indico.cern.ch/e/susthep24), featuring keynote lectures and contributed talks that encompass a diverse range of topics in high-energy physics. The goal of the workshop was to focus on the long-term environmental impacts of research facilities, computing, and the challenges faced by researchers and institutions, while also offering a platform for proposed solutions to tackle climate change.

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1. Introduction

There is a broad scientific consensus that the Earth has been warming since the Industrial Revolution, primarily due to human activities such as fossil fuel combustion, methane emissions, and deforestation. In 2023, we recorded the warmest year since 1850, resulting in severe heatwaves and extreme weather events, causing significant casualties and significant socio-economic disruptions. The 2015 Paris Agreement [1] aims to limit the global surface temperature warming to 1.5°C compared to that in the 1800s, which requires a 50% reduction in emissions by 2030. However, current emissions far exceed this target. The importance of a 1.5°C limit is highlighted by the fact that the temperature difference between now and the last ice age (around 12,000 years ago) is only about 5°C. In 2023, the global surface temperature was already $1.45 \pm 0.12\,^{\circ}$C higher than it was in the late 1800s [2]. If temperatures were to rise by 4°C in the next 50 years, as predicted by the Intergovernmental Panel on Climate Change (IPCC) under high emissions, it could lead to disruptions beyond what our current civilization can withstand.

In high-energy physics, significant greenhouse gas emissions arise from the construction and operation of large accelerator facilities, leakage of detector gases, and operation of large distributed computing facilities. The third edition of the Sustainable High Energy Physics Workshop, held online from June 10 to 12, 2024, aimed to explore sustainable practices in accelerator operations, including advancing research into materials that can help mitigate these emissions. Focusing on the relationship between high-energy physics and global warming, the workshop sought to enhance sustainability efforts and contribute to global climate crisis mitigation. Over the course of three days, participants examined various sustainable initiatives within the HEP community and beyond. The event attracted 233 registered participants from 31 countries and featured 8 plenary talks, 23 submitted presentations, and an interactive session on calculating carbon footprints comparing professional and personal contexts. Key discussions emphasized the importance of utilizing eco-friendly electricity grids to minimize carbon footprints, implementing energy-saving and recycling strategies, and conducting life cycle assessments of particle colliders, among many other noteworthy initiatives.

2. Session Summaries

The workshop commenced with an insightful overview of climate change presented by our keynote speaker, Prof. Jyoti Parikh (IRADe), who was a recipient of the Nobel Peace Prize given to the IPCC authors in 2007 and was a member of the former Prime Minister's Council on Climate Change in India. The talk focused on "Energy System and Technology Choices", and the need for integrating renewable sources such as wind and solar power, as well as promoting better energy storage and digital technologies. Prof. Parikh highlighted that it is feasible to achieve economic development with reduced emissions but raised the crucial question of whether we will meet the necessary deadlines, sparking engaging discussions among attendees. The intersection of particle physics and sustainability was explored in Prof. Boisvert's (Royal Holloway) talk, which covered various sources of carbon emissions within the field and proposed several compelling solutions for both short- and long-term sustainability research goals. Such solutions are further elaborated upon

in the following sections summarizing the key topics discussed during the workshop[1].

2.1 Sustainable Accelerators and Detectors

One of the key discussions during the workshop centered on the need for sustainable accelerators, which are vital not only for advancing scientific research but also for preserving environmental balance. Prof. Yoshioka (KEK, ILC) focused on the need for life cycle assessments (LCA) of future accelerators and current developments in material sciences as well as the role of the Ichinoseki forest in absorbing CO_2 emissions in the proposed site for ILC construction. In addition, Prof. Yoshioka stressed the importance of collaborating with local communities to make sustainability accessible to all segments of society. An excellent talk by Ms. Suzanne Evans (ARUP) delved deeper into LCAs from the industrial perspective, analysing the environmental impacts of tunneling for CLIC and ILC, amongst several other contributors. Proposed solutions for reducing carbon emissions were also discussed. Mr. Ben Shepherd (Particle Accelerators and Beams Group, IOP) highlighted novel accelerator technologies, such as permanent magnets and thin film superconducting cavities which can aid in reducing the carbon footprint in the near future. Several sustainable initiatives at major particle physics facilities such as Belle-II, DESY, CERN, ISIS-II, C^3, CEPC were highlighted in this session. One example is reducing power consumption and recovering thermal energy, by CERN's initiative to use LHC cooling water for heating homes in Ferney-Voltaire. Furthermore, Dr.Thomas Roser (BNL) presented the ICFA strategy for sustainable accelerators, while Prof. Jorgen D'Hondt (Vrije Universiteit Brussel) outlined the Horizon Europe project Innovate for Sustainable Accelerating Systems (iSAS), among other efforts.

Along with developing sustainable strategies in accelerator physics, it is equally essential to estimate carbon emissions in detector operations to understand where emissions are originating from. Gaseous detectors play a significant role in greenhouse emissions related to particle detection, cooling, and insulation [3]. The workshop extensively covered ongoing research aimed at developing eco-friendly gas mixtures for Cherenkov detectors, resistive plate chambers, and other types of detectors, with a strong emphasis on creating more efficient, leak-free, and recirculating systems.

2.2 Green Computing

Greener computing in particle physics is crucial for minimizing the environmental impact of large-scale experiments and data processing. By optimizing code and energy consumption in servers, storage, and cooling systems, scientists can significantly reduce their carbon footprint. Innovations such as energy-efficient algorithms, eco-friendly data centers, and improved hardware design are essential steps toward sustainable computing practices. Dr. Lannelongue (Univ. of Cambridge) explored various novel initiatives, such as the Green Algorithm project as well as a digital sustainability certification, Green DiSC. Dr. Lannelongue emphasized that collaborative efforts among grassroot movements, funding organizations, institutes, and the industry are crucial for making progress in this area. Along with software developments, sustainable hardware for LHC experiments, such as the High-Low project at Valencia was discussed by Prof. Oyanguren (Univ. of Valencia). Additionally, Mr. Brüers (DESY) provided an overview of resource-aware knowledge

[1]Please be advised that this is not an exhaustive list of summaries and is subject to the author's discretion. For a comprehensive overview of all presentations, kindly refer to the Indico page.

with focus on processing data smartly, using efficient software and prolonging the usage of hardware products.

2.3 Interdisciplinary initiatives on sustainability

In addition to high-energy physics, the workshop actively encouraged discussions from other disciplines engaged in sustainable science. Dr. Bender (Argonne National Lab) presented a techno-economic analysis of renewable energy generation at the South Pole, exploring options for solar and wind energy along with energy storage solutions. Ms. Wagner (Uni Würzubrg) approached the climate crisis from an astronomical perspective, highlighting Astronomers for Planet Earth, a global network dedicated to sustainable research goals. Another engaging talk addressed the future of meetings in the particle astrophysics community, emphasizing the importance of reducing in-person gatherings for the benefit of both the environment and researchers. Dr. Brandt (Univ. of Cambridge) discussed the carbon footprint of the concrete industry and introduced muon tomography as a novel technique for assessing reinforced concrete, which could significantly reduce carbon emissions. Dr. Coadou (CPPM) presented Labos 1point5, an initiative aimed at lowering the carbon footprint of research infrastructure by providing tools, webinars, and scientific papers. Lastly, Dr. Bouman (Univ. of Groningen) examined the psychological factors influencing sustainable energy transitions, highlighting the importance of understanding societal perceptions and behaviors. Dr. Paul (Northeastern University) advocated for optimizing scientific efforts to minimize environmental impact while balancing scientific progress with ecological preservation [4].

2.4 Know Your Footprint Workshop

The workshop concluded with an engaging interactive session focused on the "Know Your Footprint" tool, presented by the Young High Energy Physicists (yHEP) Organization and facilitated by Mr. Bhalla (Univ. of Freiburg). This tool assists participants in calculating their individual carbon footprints. Emissions were categorized into four major areas: experiments associated with large collaborations, resource consumption in laboratories and universities, energy use in computing, and work-related travel [5].

The discussions surrounding carbon emissions, both at personal and professional levels, sparked lively conversations about understanding the sources of these emissions and identifying practical strategies for reduction in daily life. Participants explored various approaches to minimize their impact, including reducing flight emissions, promoting the need for virtual meetings, creating eco-friendly office environments, and adopting greener computing practices. These dialogues emphasized the importance of individual and collective actions in addressing climate change.

3. Conclusion

Halting global warming is an urgent priority for humanity, with the goal of reducing greenhouse gas emissions to nearly zero by 2050. While collaboration among local communities and industries is essential, individual actions, though seemingly minor, contribute significantly to our collective efforts for a sustainable future. Additionally, integrating renewable energy sources into large scale HEP facilities can further enhance sustainability efforts in the field, ensuring that scientific advancements do not come at the expense of the environment. In conclusion, the Sustainable HEP

2024 workshop presented a range of innovative ideas and practical solutions designed to reduce the environmental impact of high-energy physics. The event highlighted the HEP community's strong commitment to sustainability while advancing scientific knowledge and fostering collaborative efforts for a more sustainable future.

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