frontiers | Frontiers in Physics

TYPE Editorial
PUBLISHED 04 April 2023
DOI 10.3389/fphy.2023.1177534

OPEN ACCESS

EDITED AND REVIEWED BY
Cinzia Da Via,
The University of Manchester,
United Kingdom

*CORRESPONDENCE
Alessandro Tricoli,
atricoli@bnl.gov

SPECIALTY SECTION
This article was submitted to Radiation Detectors and Imaging, a section of the journal Frontiers in Physics

RECEIVED 01 March 2023
ACCEPTED 24 March 2023
PUBLISHED 04 April 2023

CITATION
Tricoli A, Azzi P, Merkel P and Shiltsev V (2023), Editorial: Novel ideas for accelerators, particle detection and data challenges at future colliders.
Front. Phys. 11:1177534.
doi: 10.3389/fphy.2023.1177534

Editorial: Novel ideas for accelerators, particle detection and data challenges at future colliders

Alessandro Tricoli[1]*, Patrizia Azzi[2], Petra Merkel[3] and Vladimir Shiltsev[3]

[1]Brookhaven National Laboratory (DOE), Upton, NY, United States, [2]National Institute of Nuclear Physics of Padova, Padova, Italy, [3]Fermi National Accelerator Laboratory (DOE), Batavia, IL, United States

KEYWORDS

future colliders, detectors, instrumentation, computing, simulation, Higgs factories, event reconstruction

Editorial on the Research Topic
Novel ideas for accelerators, particle detection and data challenges at future colliders

1 Introduction

Since the observation of the Higgs boson by the ATLAS and CMS Collaborations at the Large Hadron Collider (LHC) in 2012 at CERN laboratory, which led to the 2013 Nobel Prize to Prof. Peter Higgs and Prof. François Englert, a strategic plan is being developed by the international communities of particle physicists. This foresees new collider experiments that study the properties of the Higgs boson, i.e., Higgs Factories, look for anomalies in the wider realm of the Standard Model of particle physics by performing precision measurements, for example, in the electroweak sector, and push the energy reach of particle beams to explore the unknown in the multi-TeV energy range. These new accelerator projects will follow the High Luminosity run of the LHC (HL-LHC) that is planned to start in 2029 and is expected to conclude its data-taking period about 10 years later. The most prominent proposals for Higgs Factories are electron-positron colliders, either circular or linear. In recent years, the possibility of a muon collider has attracted new and revived interest both as a Higgs Factory and as an energy-frontier machine. Proton colliders are proposed as multi-TeV machines, while also allowing a copious production of Higgs bosons. Such proton colliders will generate unprecedented radiation levels in regions close to the collision points, making even more challenging the application of new technologies that have to be highly radiation tolerant. Several accelerators are proposed to collide electrons against hadrons, which will probe the inner structure of hadrons, and may also be sensitive to new physics. Other interesting projects have been proposed, for example, the photon-photon collider, the very high-energy electron collider, *etc.*

These accelerator projects set very stringent requirements, for example, in accelerator, particle detector technologies, readout and event triggering electronics, data transmission, and computing, as well as in the algorithms for the reconstruction of collision events, particle identification, and simulations. Advances in such technologies will not only make possible the realization of future particle physics experiments, but will also greatly benefit other areas of scientific research, industrial applications and, in the longer term, will have a significant societal impact.

This Research Topic provides a small window into the prospects for future accelerator-based experiments and focuses on novel technologies that go beyond the state-of-the-art of their fields, and push the boundaries of innovation with the goal to make giant leaps forward in the understanding of what is currently unknown. The topics present in this review include proposals for future accelerators, physics prospects at such accelerators, and research and development for the detectors.

2 Future colliders

Energy frontier particle colliders–arguably, among the largest, most complex and advanced scientific instruments of modern times–for many decades have been at the forefront of scientific discoveries in high energy physics. Due to technology advances and beam physics breakthroughs, the colliding beam facilities have progressed immensely and now operate at energies and luminosities many orders of magnitude greater than the pioneering instruments of the early 1960s. While the LHC and the Super-KEKB factory represent the frontier hadron and lepton colliders of today, respectively, future colliders are an essential component of a strategic vision for particle physics. Conceptual studies and technical developments for several exciting near- and medium-term future collider options are underway internationally.

In this Research Topic of articles, presented in depth are various aspects of the challenges, facing the future colliders. First of all there are critical beam physics considerations, such as luminosity reach of the different types of colliders, energy efficiency, particle sources and acceleration techniques, limitations due to beam instabilities, *etc.* Integrated machine design proposal of several most matured colliding beam facilities are presented for several e^+e^- Higgs Factories (high luminosity for detail explorations of the Higgs and electroweak physics), for electron-ion colliders, and energy frontier muon and large hadron (proton-proton) superconducting super-colliders.

Critical for the largest scale machines are core accelerator technologies as they directly affect facility's energy reach, size, energy consumption, cost and performance. This Research Topic includes reviews of the technologies of the accelerators' magnets and RF (radio-frequency) acceleration systems–these are linchpins in the progress toward future colliding beam facilities.

3 Physics and performance prospects

This is a unique and exciting time for the particle physics community, as the field is at a critical cross road. Despite the great success of the Standard Model, several fundamental properties of the Universe remain unexplained. Among them there is the mechanism behind the electroweak symmetry breaking, the nature and origin of dark matter, flavour and neutrino masses, the tantalizing strong CP problem, the origin of baryon asymmetry, quantum-gravity *etc.* Several future experiments are proposed to address some of these questions. These experiments include e^+e^- Higgs Factories and multi-TeV colliders. Their goals are to search for new physics beyond the SM, either directly, i.e., by producing new particles, or indirectly, i.e., by measuring precisely deviations from the expected properties of SM particles. In the absence of experimental evidence for new physics, in the past decades multiple theories and models have been proposed. Several of them predict the existence of long-lived particles, such as heavy neutral leptons, axion-like particles, new Higgs boson states, exotic decays of the Higgs boson, weakly interacting massive particles, *etc.* For the success of any future collider experiment, it is critical to efficiently and accurately reconstruct particles in collision events. As an example, the reconstruction of tau leptons is challenging at the LHC and will be important at future colliders to more precisely constrain the Higgs coupling to tau leptons and to increase the sensitivity to new physics. Towards this goal it will be beneficial to implement machine learning algorithms as well as improve the granularity of future detectors. As another example, the study of the substructure of jets of hadrons has allowed LHC experiments to exceed expectations in accessing new physics parameter space. Recent advances in experimental and theoretical techniques in jet substructure will play an important role at future lepton and hadron colliders. However, such techniques will rely on optimized detector designs, such as higher granularity, timing information, *etc.* This Research Topic presents an overview of the physics goals of future colliders at the energy frontier, in an international context, and some examples of prospects for the reconstruction and identification of particles in collision events to improve the potentials for future discoveries.

4 Detector and computational technologies

Detectors at future colliders will face several new challenges. At lepton colliders they must be made of light materials, i.e., low material budget, and highly granular, while at hadron colliders they must withstand high radiation levels. Furthermore, particle identification *via* the simultaneous measurement of several quantities, such as particle hit position, time and energy deposited, is expected to become even more important at future collider experiments, given the needed precision and thanks to recent advances in technologies. Among them, novel types of fast-timing detectors are being investigated and their radiation tolerance properties are being studied. The data acquisition and data transmission will also play a critical role. Recent studies show that multi gigabit wireless data transmission is possible and can become an alternative to the use of cables and optical links with the potential of improving the detector performance. The main advantage of such a new technology will be the transmission of large amounts of data with low power in a high radiation environment, such as at hadron collider experiments. Quantum sensing and quantum computing are expected to revolutionize particle detection and computational techniques. More specifically, quantum systems of low-dimensions as well as the ensembles of quantum systems might lead to improved calorimeter, tracking and timing detectors. In parallel, quantum computing might help solve the growing problem of the large data sets that are expected at future colliders, especially at hadron colliders, together with innovations in machine learning techniques.

10.3389/fphy.2023.1177534

Modern collider experiment rely on the accurate calculation and modeling of particle collisions and the simulation of the particle interactions with active and passive detector components. Particle simulations are important in the design stage of an experiment as well as in the optimization of the analysts strategy and ultimately in data analysis. In the past decades Monte Carlo generators and detector simulations have made great progress and have become indispensable tools for collider physics. It is expected that such tools will play an equally important role in the future, adapting to new computing platforms and computational techniques.

Author contributions

AT, VS, PM, and PA wrote this editorial contribution.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.