Grand Challenges

The Collaborative Computational Project in Theoretical and Experimental Particle Physics (CCP-TEPP)

Over the next five to ten years, CCP-TEPP will develop advanced computational methods to process unprecedented volumes of experimental data and deliver high-precision theoretical predictions. This transformation will enable next-generation particle physics research to uncover new phenomena and make breakthrough discoveries about the fundamental nature of matter and the universe

The Community

Over the next decade, research in theoretical and experimental particle physics (TEPP) will be driven by a tenfold increase in data from facilities such as the High-Luminosity Large Hadron Collider (HL-LHC) and next-generation neutrino experiments. This scale of data and complexity demands a transformation in computational methods: traditional approaches cannot cope with the challenge of processing, simulating, and analyzing these vast datasets at the precision needed to uncover new physics beyond the Standard Model—such as understanding the matter–antimatter asymmetry, probing the Higgs boson in detail, and exploring phenomena that could reshape our view of the universe.

CCP-TEPP builds on the UK's strong culture of collaboration in TEPP. Its aim is to support researchers across theory and experiment, alongside global academic and industrial partners, in developing and maintaining advanced computational methods and software frameworks. These tools will modernize TEPP workflows for modeling, data processing, and analysis to meet the requirements of next-generation experiments..

The Challenge

To transform computational methods to handle an order-of-magnitude increase in data and complexity from future particle physics experiments and theoretical developments.

The grand challenge for CCP-TEPP is to transform computational methods so they can handle an order-of-magnitude increase in data and complexity from next-generation particle physics experiments, enabling discoveries that redefine our understanding of the universe.

Experiments must process unprecedented data volumes from facilities such as the HL-LHC, neutrino observatories, and dark matter searches—enabling simulation, real-time triggering, filtering, and

reconstruction while maintaining accuracy. For theory, the challenge is to produce predictions with the precision required to guide and interpret these experiments, through high-accuracy lattice QCD calculations, exploration of physics beyond the Standard Model, and simulations of extreme conditions such as the quark–gluon plasma.

Meeting these demands requires a major transformation of computational methods and workflows, integrating advanced algorithms, AI-driven approaches, and exascale computing to achieve the speed, scalability, and precision needed across the entire pipeline. This transformation is essential for the UK to maintain and strengthen its global leadership in uncovering new physics and answering the most profound questions about the universe.

The Solution

To deliver scalable, modular frameworks that exploit HPC, GPU acceleration, and AI-driven enhancements for real-time data processing and high-precision theoretical calculations

Over the next decade, CCP-TEPP will lead the development of next-generation computational frameworks for theoretical and experimental particle physics that combine high-performance computing (HPC), GPU acceleration, and advanced algorithms with emerging AI techniques. These tools will enable researchers to process and analyze the unprecedented data volumes expected from the High-Luminosity LHC and future neutrino experiments in real time, while maintaining the precision required for discovery.

The community will deliver scalable software platforms optimized for modern heterogeneous architectures—multicore CPUs, GPUs, and exascale systems—ensuring particle physics workflows can fully exploit current and future computing resources. AI and machine learning will be integrated strategically, building on TEPP's leadership in these fields, for example to accelerate event selection and simulation, but the foundation will remain robust physics-based algorithms validated against experimental and theoretical benchmarks.

CCP-TEPP will also provide modular frameworks for detector simulation, event generation, and theoretical calculations such as lattice QCD and beyond the Standard Model studies. These frameworks will allow rapid incorporation of new physics models and experimental insights, dramatically reducing analysis timelines and computational costs while improving automation. By combining HPC, GPU acceleration, and AI-driven enhancements, CCP-TEPP will modernize particle physics software, strengthen UK leadership in global collaborations, and train the next generation of researchers in cutting-edge computational science.

The Outcome

To further the UK's leadership in TEPP by creating a next generation of software frameworks for data analysis and theoretical calculations to enable world-leading discoveries.

Grand Challenges

A modern, scalable computational ecosystem that empowers UK researchers to deliver world-leading breakthroughs in particle physics and advance STFC's strategic vision. CCP-TEPP will underpin discoveries that address the most fundamental questions about matter and the universe, while reinforcing the UK's position as a global leader in international collaborations tackling these challenges.

By integrating HPC, GPU acceleration, and AI-driven enhancements into robust physics-based workflows, CCP-TEPP will also foster partnerships with industry to drive innovation in advanced computing technologies with benefits beyond academia. This combination of scientific leadership, technological innovation, and international collaboration will ensure the UK remains at the forefront of particle physics and computational science, while cultivating a highly skilled workforce in advanced computing and AI integration.

More Information

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