The international journal of science / 18 January 2024

nature

US and Europe should team up on muon collider

A feasibility study for a muon smasher in the United States could be an affordable way to maintain particle-physics unity.

Last month, a group of researchers in the United States presented a rousing vision for the future of high-energy particle physics. The recommendations from the Particle Physics Project Prioritization Panel (P5) came in response to a request from funding agencies to set out priorities for building new facilities. One stood out: to push for the development of an entirely different type of particle collider, called a muon collider. It's a bold suggestion that could shape the face of high-energy physics for decades to come. It is also a rare opportunity to continue the global unity that characterizes much of the particle-physics community. Laboratories across the rest of the world, but in particular at CERN, Europe's particle-physics laboratory outside Geneva, Switzerland, should contribute to it.

Since the discovery of the atomic nucleus in 1911, studying the collisions of atoms or particles has been the chief method for understanding the detailed nature of subatomic matter and the forces that govern its behaviour. In modern experiments, collisions typically happen between highly focused, accelerated beams of electrons or protons travelling in opposite directions. Researchers at CERN's Large Hadron Collider (LHC), the world's highest-energy accelerator, discovered the Higgs boson particle in 2012 by smashing protons together and seeing what massive particles these highly energetic collisions produced.

A muon collider would use beams of muons, particles similar to electrons but around 200 times heavier. It would enable tests similar to those run in proton-beam experiments, but releasing ten times as much energy, and with lower energy consumption — potentially making it much cheaper. Such a machine could also explore interactions that have been difficult to study with other colliders, allowing researchers to test the established theory of elementary particles, called the standard model, in new ways.

Getting there will be neither easy nor quick. For a start, researchers do not yet know for sure that it can be done. Muons are routinely created in high-energy-physics labs, but they are unstable and quickly decay into other particles. The technology to accelerate muons into tightly focused beams before they disappear is still in its infancy.

To make it happen, the P5 authors call for a US "muon shot" — language intended to evoke images of the 1960s and 70s Apollo Moon programme that landed men on the Moon. The aim would be first to develop the technology to the point of proof of principle, and ultimately to build a full-size muon collider on US soil.

> **"It is not possible to completely take geopolitics out of the equation."**

This, the panel says, would restore US leadership in physics of the highest energies, which, since the 1993 cancellation of the country's own huge proton collider, the Superconducting Super Collider, has mostly been ceded to Europe, CERN and the LHC.

Looking to a future beyond the LHC, CERN completed a future strategy study in 2020 that also called for muon-collider research and development. The institution subsequently allocated seed funds, with money from the European Union and some individual member countries, to study the plan's feasibility, setting up the International Muon Collider Collaboration.

The group does not have enough money to get started, however. Indeed, CERN's preferred vision is to build not a muon collider, but a Future Circular Collider (FCC) instead, at CERN itself. This project, which comes with an anticipated price tag of more than US$30 billion, would involve constructing an accelerator tunnel more than 90 kilometres in circumference, three times longer than that hosting the LHC. This would initially host an electron–antielectron linear collider, to study the detailed properties of the Higgs boson, and would later be replaced with a proton collider capable of producing energies seven times higher than the LHC. CERN's rationale for favouring such an approach (other than for Europe to retain its prominent position in the field) includes the fact that alternative technologies — such as muon colliders and the acceleration of protons using waves of plasma — are as yet unproven.

But the proton-smashing stage of CERN's FCC project would also necessitate pushing several technologies — in particular, superconducting magnets — substantially beyond their current state. Even assuming that it gets funded and is eventually built, the FCC's proton collider probably would not start up until the 2070s; hence the researchers' proposal for an intermediate electron collider. CERN physicists think that this work will keep them busy studying the Higgs, and keep the lab relevant in the intervening decades.

Even some of the physicists backing the FCC acknowledge that there is not yet a strong scientific case for building the collider. So far, experiments have failed to find any substantial hints of physical phenomena beyond those described in the standard model occuring at the higher energies to be generated by the FCC. And there could be cheaper and simpler ways to study the Higgs, such as with a linear electron–antielectron collider. As well as being cheaper than a circular 'Higgs factory', a linear collider would also enable more-precise studies of the Higgs boson, some physicists say.

Given the amount of public money involved, it is not possible to completely take geopolitics out of the equation. But the rationale for such projects does not need to be about the leadership of particular countries or regions. A more effective way to argue for a muon collider is for physicists to see this as a genuinely global endeavour. It offers an opportunity for particle physicists in the United States, at CERN and elsewhere to put their heads together and

nature

establish whether a muon collider is feasible and, if so, at what cost, and who can contribute expertise and facilities. If it works out, particle physicists all over the world might gain an exciting – and potentially more affordable – way of probing nature.

Norway's approval of sea-bed mining undermines efforts to protect the ocean

The country's decision to permit deep-sea extraction of valuable minerals could do irreparable harm.

When Norway and Palau announced in 2018 that they were co-chairing the High Level Panel for a Sustainable Ocean Economy (now called the Ocean Panel), many researchers were hopeful. Fourteen governments, collectively responsible for 40% of the world's coastlines, pledged to sustainably manage 100% of their exclusive economic zones (national waters) by 2025. They explicitly looked to scientists to guide them in how to achieve their goals. In 2020, the panel's leaders backed five priorities proposed by its science advisers that included ways to decarbonize the shipping industry and to manage seafood production sustainably. "Rarely has scientific research been so keenly sought by political leaders, or so readily accepted as the basis for policy," said Norway's then-prime minister Erna Solberg.

To support the initiative, the Nature Portfolio journals collaborated with the Ocean Panel and published a collection of articles in December 2020. *Nature* recommended that independent measures should be included to hold the members of the panel, which now includes 18 nations, accountable for their pledges. Such indicators were needed because "governments change", we noted in an editorial (see *Nature* **588**, 7–8; 2020). "The panel's members know that, one day, they will need to pass on their responsibilities. In some cases, their successors will want to continue their policies, but in others, they won't – as we know all too well."

An independent system of accountability never materialized. In 2021, Norway elected a new government. And last week, its parliament voted to allow the controversial practice of sea-bed mining (see page 435). This decision goes against the advice of the Norwegian Environment Agency, the Ocean Panel's scientific advisers and other researchers. The scientists all say that too little is known about the deep-sea ecosystem – such as its biodiversity and its interactions with other ecosystems – to safely mine the sea floor. Researchers also question Norway's suggestion that sea-bed mining will strengthen the country's economy and that terrestrial supplies of metals such as manganese and cobalt, which are used in batteries and other electronics, are insufficient to support the transition to a low-carbon economy. Researchers are both baffled and deflated by the decision. Norway's about-face isn't just a setback for the country's sustainability efforts; it undermines the progress and the credibility of the Ocean Panel.

> "The political energy and enthusiasm for the panel gave scientists a real sense that this time would be different."

The vote allows companies to explore whether critical minerals, such as sulfide and manganese, on the sea floor could be extracted profitably. Commercial-scale mining will require another parliamentary vote – a compromise the government agreed on to gain support from other political parties. Astrid Bergmål, the secretary of state for the Ministry of Petroleum and Energy, told *Nature* that the vote "does not mean extraction starts" immediately. Bergmål added that Norway will ensure that its sea-bed activity is in line with its international obligations, including the 1982 United Nations Convention on the Law of the Sea and the 1992 UN Convention on Biological Diversity.

Researchers are not naive. They don't expect politicians to take all their advice on board. But the political energy and enthusiasm for the panel gave scientists a real sense that this time, things would be different. In hindsight, signs to the contrary were already there by 2021. In January that year, the Norwegian government first announced its intention to mine minerals on the sea floor. And it continues to issue permits for offshore oil and gas drilling.

This vote has made some of the panel's current and former scientific advisers wonder whether other nations might be better placed to take over Norway's leadership position. The initiative does not, however, have a publicly accessible system for choosing its chairs. The panel's secretariat did not respond to *Nature*'s questions about its governance arrangements, nor did it clarify whether other members could sanction Norway and, if this was the case, whether they planned to do so.

All members have made progress in some areas, according to the Ocean Panel's 2022 report (see go.nature.com/3u3r3be). For example, Chile has assigned some protection to 43% of its waters and, last year, it began a more ambitious programme to sustainably manage all its marine resources. Kenya has set up what the panel says is the world's first community-led project to protect and restore mangrove forests, an effort that will be supported by the sale of carbon credits.

Overall, the panel's secretariat reports that its member countries made 652 commitments towards their shared goal of sustainably managing the ocean resources in their national waters by 2025. Of the 345 analysed in the report, 54% have been accomplished and 40% are showing progress. Norway's Prime Minister Jonas Gahr Støre jointly wrote in the progress report: "The Ocean Panel was established to lead the way, and we need to live up to this ambition." That is why Norway's parliament must reverse its decision. If it is unable to do so, the government should acknowledge that the country has lost any claim to be an ocean-protection leader.