

# Advancing Vacuum Technology at CERN: From Future Accelerators to Gravitational-Wave Observatories

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Vacuum technology at CERN has continuously evolved in response to the demanding requirements of new scientific facilities. The Large Electron–Positron Collider (LEP), building on the pioneering developments of the Intersecting Storage Rings (ISR), and later the Large Hadron Collider (LHC) and its upcoming upgrade, have driven substantial advances in the design and operation of accelerator vacuum systems.

Today it is well established that the physico-chemical properties of the first atomic surface layers play a crucial role in determining vacuum performance. Consequently, the functionalisation of surfaces exposed to intense particle beams—through techniques such as thin-film coatings and roughness control—has become a key element in the reliable operation of these complex instruments. Current developments in such fields at CERN are strongly driven by the study of the Future Circular Collider (FCC), a proposed 91-km-circumference electron–positron collider.

However, as vacuum equipment for future facilities may represent a major cost driver, optimisation must increasingly consider the entire lifecycle of the vacuum equipment. In this context, even technologically elegant solutions must be validated through detailed cost, industrialisation, and optimized performance analyses.

Beyond accelerators, similar challenges arise in the vacuum systems required for next-generation gravitational-wave observatories. In the Einstein Telescope and Cosmic Explorer projects, for example, more than 100 km of large-diameter ( $\geq 1\text{m}$ ) vacuum tubes will need to operate in the low  $10^{-10}$  mbar pressure range.

This contribution will highlight key innovations in vacuum technology pioneered for the LHC and discuss the developments required for the FCC. It will also review CERN’s ongoing holistic investigations of the vacuum tube system for the Einstein Telescope, which are leading toward the project’s Technical Design Report.