

Unraveling the secrets of the universe: novel sensitivities through quantum technologies and machine learning

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The development of the universe from the Big Bang to its present structure is described very well by the standard cosmological Λ CDM model, but some very important questions remain unresolved: What particles make up the so-called dark matter, which accounts for over 80% of the matter in the universe? Or does dark matter consist of a primordial class of black holes, similar to those whose mergers we have been observing for several years with gravitational wave detectors? How large is the neutrino mass scale and what role do these elusive and most abundant particles, which are one billion times more abundant and at least one billion times lighter than atoms, play in structure formation?

This talk will report on the state of current research using the example of the KATRIN neutrino mass experiment and the XENON dark matter experiment. The sensitivity of these experiments is already extremely high, enabling them to deliver important new results, but so far they have only been able to set upper limits on neutrino mass and dark matter.

In order to significantly increase the sensitivity once again in the field of low energy (astro)particle physics, interdisciplinary approaches using quantum technology as well as modern AI methods such as machine learning are of particular importance, as will be explained using examples. At XENON, machine learning methods and a coherent quantum effect made it possible for the first time to see neutrinos from the sun with a detector covering only 2 cubic metres. Another example from our institute, in collaboration with geophysicists, is the application of machine learning and a network of seismometers to reduce the influence of seismic noise on the next generation gravitational wave detector ET. And the next-generation project KATRIN++ aims to achieve differential sub-eV energy resolution using a quantum sensor array or a time-of-flight spectroscopy method with an electron tagger based on quantum sensor technology.

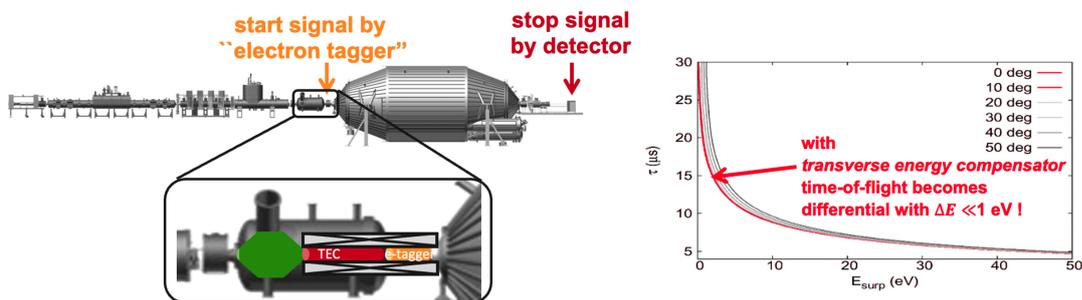


Figure 1: Time-of-flight spectroscopy for KATRIN++ enabled by transverse energy compensator and electron tagger