INFN interests in Quantum Science and Technology for Particle and Astroparticle Physics

R. Tripiccione[1] T. Boccali[2], G. Carlino[3], L. Dell'Agnello[4], C. Grandi[5], D. Lucchesi[6], G. Maron[4], D. Menasce[7], L. Perini[8], D. Salomoni[4], P.Vicini[9], A. Zoccoli[10]

[1] *University and INFN Sezione di Ferrara*
[2] *INFN Sezione di Pisa*
[3] *INFN Sezione di Napoli*
[4] *CNAF Bologna*
[5] *INFN Sezione di Bologna*
[6] *University and INFN Padova*
[7] *INFN Sezione di Milano*
[8] *University and INFN Milano*
[9] *INFN Sezione di Roma*
[10] *University and INFN Bologna*

Abstract

INFN sees that Quantum Sciences and Technologies will have an increasingly important role in particle and astroparticle physics, in the time frame relevant for this Snowmass process. In general terms, the know-how available in the area of particle and astroparticle physics will be relevant in the near future for the development of better quantum devices and to increase their immunity to noise. Conversely, recent progress made independently on quantum technologies by different research communities will allow significant steps for the development of advanced detectors, mainly in the area of dark/exotic matter searches. On a longer time scale, the disruptive changes in the computational models made possible by quantum simulation and quantum computing will deeply affect the computing strategies of particle/astroparticle physics for experiments and for theory.

Scientific and technological contest

Research and Development in Quantum Sciences and Technologies has seen a dramatic boost in recent years. Strong support has been given by governmental agencies in the US, Europe and Asia and industry is deeply involved in this effort: the European Commission has launched the Quantum Flagship Program[1], and large programs exist in the US. Independent industrial developments play now a fundamental role in the field. So far, the particle and astroparticle physics community has shown limited interest in this area; this has changed dramatically in very recent time, as major particle physics laboratories have begun to focus on this research and development area. This is welcome, as a close collaboration has important advantages, especially when approaching Quantum Science and Technologies from the HEP point of view.

The role of HEP in quantum science and technology is inherently twofold:

1https://qt.eu/

1. The know-how developed by the HEP community to pursue its own research goals has the inherent potential to play a significant role in the development of improved quantum devices, with a potential dramatic impact in the evolution roadmap towards quantum computing. As an example, 3D superconducting cavities, originally developed for particle accelerators, can be easily modified to operate in the quantum regime, and promise to enable qbit architectures with coherence time order of magnitude better than possible with currently available devices.
2. Conversely, some of the technologies independently developed within the quantum sensing community can be blended with that of the HEP community to develop more advanced detectors, mainly in the area of dark matter detection and for tests of fundamental quantum mechanics in extreme conditions. As an example, increasing the coherence time of superconductive cavities in spite of the presence of strong magnetic fields plays a crucial role in the development of order of magnitude more sensitive detectors for axions or dark photons.

The two points discussed above refer to research and development activity that must be carefully considered and pursued in the frame time relevant for this Snowmass exercise. In a longer time frame, as -- possibly with the contribution of the HEP community -- quantum simulation and quantum computation become more mature, disruptive changes in the computing model for HEP experiment and theory are to be expected; all areas will be affected, from Lattice QCD simulations to the whole computing model of HEP and Astroparticle experiments. It is crucial that at this point in time the HEP community prepares for this long term transition. Even if no strong and large scale impact can be reasonably expected in the next decade, experimenting with the available quantum simulation and computing technologies must be strongly encouraged, in order to identify all useful application areas and to be ready for an early and useful adoption.

Objectives, Methodology and Challenges

It is now beyond any reasonable doubt to assume that Quantum Technologies will have a very strong and transformative impact on how HEP research will be conducted in the not too far future. Starting from this assumption, INFN feels that a key objective for the HEP community in the area of Quantum Science and Technologies is to engage in a diversified set of Quantum Science research directions. The main overall efforts of this research effort are to: i) contribute to the development of quantum technologies and devices with improved performance, able to shorten the development framework that will lead to application-enabling quantum computing; ii) bring to practical maturity the conceptual advantages of quantum coherence in order to develop (and use) particle detectors able (in principle and in practice) to move forward the current limits on dark and exotic matter; and iii) understand, at the conceptual and theoretical level, the full range of disruptive computational options that quantum computing will make available to HEP, at both the theoretical and experimental level. As the computational landscape will be necessarily dramatically at variance from the present one, an early process must be started now, using the available quantum computational resources, in order to explore the most promising development directions.

In general, HEP institutes and funding agencies should consider the development of quantum inspired development as an important part of their core research activities, both in the direction of improving quantum devices and in the direction of adapting quantum devices to become new particle detectors.

This research endeavor is best done in collaboration with non HEP partners. Options to collaborate with industrial companies or other government and private agencies already active in this field must be actively pursued. Likewise a stronger participation of HEP institutions and Funding Agencies in large scale national and international initiatives must be strongly encouraged; finally stronger links with those parts of the condensed matter community active in similar research directions must be explored.

A massive effort of education and training in quantum sciences and technologies is crucial in the community. This effort must obviously focus on the specific facets of quantum science for HEP and has as its main objectives that i) the existing HEP community has full awareness of the disruptive potential made available by quantum technologies for HEP research, and ii) a comprehensive educational effort, at the level of undergraduate and graduate studies and best made in collaboration with leading Universities worldwide, ensures that a sufficient number of new physicists, fully trained in the area of quantum science and technologies and in high energy and astroparticle physics can take an important role in future HEP research.