FET Consultation - template FET Flagships

- please limit proposals to at most five pages -

About you

- *What is your background? Are you submitting this proposal as an individual, or do you represent a community or institution?*
- CEA is a French basic and applied research institution operating in many fields. In the context of the Quantum Engineering initiative recently decided by the Commission, CEA is concerned both by basic research in quantum information technologies and quantum technologies in a broad sense, and by the transfer to industry of quantum technologies, when they fit with the industrial facilities of its R&D division, the "Division de la Recherche Technologique" (DRT). CEA has already created many spin-off high-technology companies.
- CEA strongly welcomes a European initiative on Quantum activity and fully supports a future FET Flagship on Quantum.

What is the challenge and the vision?

- *What is the grand S&T challenge and its underlying vision and what are the main objectives your initiative would address? Why is this a grand S&T challenge and what makes it a "game-changer"?*
- Quantum physics was created for explaining the interaction between light and atoms. The successful development of present world technologies (all electronics, communication and information processing devices, optics (laser,…), mechanics (alloys,…) heavily relies on the in-depth understanding of the properties of all types of materials obtained during the last century from quantum mechanics. This quantum revolution truly shaped our modern world. However, we are not yet harnessing the full power of quantum mechanics. Indeed, all degrees of freedom of physical systems have equal rights in quantum mechanics, and can behave quantum mechanically provided they are placed in adequate conditions. Pioneering experiments performed during the early 1980s demonstrated that man-made electrical circuits, much larger than electrons orbiting around the nucleus of an atom, can indeed enter the quantum regime, and be prepared in a quantum state corresponding to the superposition of currents flowing in opposite directions in a wire. Designing and making electrical circuits and, more broadly machines whose state variables, such as currents for electrical circuits, behave quantum mechanically is our goal grand vision of the second S&T quantum revolution that is just starting now. Whether or not this second quantum revolution will have, like the first one, a major impact on unforeseen domains is not known, but we are sure it has the potential to be a game changer for many technologies by making machines able to perform tasks beyond reach of classical ones, whatever the progress of conventional technologies.
- *What are the main technologies, including digital technologies, which your initiative will advance?*
- CEA mainly aims at developing basic knowledge and quantum technologies in the field of solid state quantum electrical and quantum optics devices for applications in quantum information processing (QIP).

- The emblematic QT example is the quantum computer: a quantum register consisting of a moderate number of quantum bits, thanks to its information richness and to the intrinsic parallelism of quantum evolution, could already provide a tremendous computational power, especially for some specific tasks for which our classical machines simply fall incredibly short. Although no quantum computer in the proper sense has been realized and operated yet, it constitutes a QT goal that does not seem to be so unrealistic when considering the progress achieved since the operation of the first quantum-bit circuits.
- CEA designed and operated in 2002 the first functional solid-state qubit in a superconducting circuit at CEA-Saclay; in 2012, CEA was second after UCSB to operate an elementary electrical quantum processor demonstrating the quantum speed-up of a quantum algorithm. Very recently, CEA operated the first semiconducting quantum bit fabricated in an industrial facility, namely the LETI CMOS fabrication line in Grenoble.
- CEA, strong of established credentials in the field of QIP and of already developed parterships at national (CNRS, French universities, industrial partners) and international level, now aims at becoming a key player in the development of QTs. To this aim, CEA plans to develop both basic research on a broad scope of quantum circuits of interest for information processing, and more applied research on quantum bits that could be manufactured with the techniques of microelectronics industry (which does not limit to CMOS devices).
- CEA is also involved in other areas that now become relevant for QIP:

  CEA develops in quantum optics, in the microwave range up to THz, and in photonics. CEA is developing in particular quantum photon sources and quantum optical circuits for communication and information processing.

  CEA is a main player in spintronics. Although spintronics devices are based on the spin, the most quantum property one can think of, they are still classical electrical circuits. However, some spintronics devices now enter a fully quantum regime that CEA aims at investigating and apply.

  CEA owns a broad theoretical expertise in quantum physics spanning a range of topics (quantum spintronics, topological solid-state systems, quantum algorithms, etc) of relevance to QIP and QTs in general.

Why is it good for Europe?

- *Is your initiative relevant for the European industry and what is its innovation potential that would benefit Europe's economy and/or society?*
- It is now well understood that downsizing transistors reaches ultimate limits.and that the microelectronics industry reaches a hard wall. Its development guide line, namely the celebrated Moore law, already bends. New paradigms are considered, and truly quantum electronics is one of them with a sizeable potential for a change of paradigm.
- *Are there existing international research initiatives linked to this proposal? How would this initiative position Europe with respect to other regions in the world?*
- All the relevant considerations on these issues can be found in the *Quantum Manifesto* recently transmitted to stakeholders by the research community.

- In the US, some major players such as IBM, Intel, Google, are already developing QTs at a large pace. In Europe, the framework programs have already supported a significant basic research effort, and some countries have implemented specific programs. However, the competition is so fierce that a strong EU initiative involving both basic research and industry is mandatory for really contributing to the second quantum revolution, and benefiting of its results.

<u>What would it take to do it?</u>

- *Why is Europe well positioned in terms of skills/expertise and capabilities, including industrial capabilities, to address the challenge and exploit the results? Which are the research communities to be involved?*

  Europe has been at the origin of the second quantum revolution when Aspect et al. in Orsay put the finger in 1982 on the peculiarities of the entangled states first considered by Einstein, Podolsky and Rosen in the 1930s. This was not a coincidence if the concept of quantum computing was put forward very soon after by Deutsch and Josza in UK. Europe then took the lead in this research direction, and is still at the first place in some fields, such as quantum optics and trapped ions/atoms physics, but not all of them any longer.

  The research communities concerned in Europe are already well identified and structured: Atomic/ion physics, quantum optics, solid state physics: quantum electronics, quantronics, superconducting quantum bit circuits, semiconductor qubits.

  At the industrial level, Europe still has a hand of R&D labs and companies at the forefront of research in microelectronics, communication and information processing systems.

- *What is the scale of the effort required to reach the objectives and how long will it take to do so?*

- The figures indicated by the Commissioner are basically correct.

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