Entanglement and nonlocality are nonclassical elements of quantum mechanics that have led to profound conceptual discussions on the foundation of quantum mechanics. In quantum mechanics the degrees of freedom of two and more particles can be entangled. Measurements of physical properties such as a spin, polarization, performed on entangled particles are found to be correlated. Pairs of entangled particles, so-called EPR pairs, are a significant resource in various quantum information processing schemes and have been used as toy objects for a range of fundamental studies. They lie at the heart of Einstein's “spooky interaction at a distance”, but also provide the basis of modern applications like secure encoding (quantum cryptography), teleportation and other topics in quantum information technology, and quantum computation.

The aim of the present proposal is to develop theory of the efficient source of spatially separated entangled electron pairs to be used as flying qubits in integrated and scalable on chip quantum information systems and also propose some effective methods and technology that allow for the entanglement detections and investigate its properties. This goal is in line with the European QIST Strategic Document (QIST = Quantum Information Science and Technology) that states: “Quantum Information Processing and Communication (QIPC) has the potential to revolutionize many areas of science and technology. It exploits fundamentally new modes of computation and communication. It holds the promise of immense computing power beyond the capabilities of any classical computer. and it is directly linked to emerging quantum technologies, such as, for example, quantum based sensors.” Quantum technology is an emerging new area which might have a similar impact on our society as classical integrated circuit technology. It is therefore crucial for Europe to maintain its leading role.

In the proposed project we in the collaboration with some leading experimental European research groups will work out the theory of one crucial element needed in a solid-state quantum processors, a so-called electron entangler with incorporated entanglement detectors. There is a system where spin-singlets and therefore entangled EPR pairs of electrons occur naturally. The ground state of a superconductor is formed by a condensate of so-called Cooper pairs which usually are electron pairs in a spin-singlet entangled state with some binding energy. Since there are many overlapping Cooper pairs in a metallic superconductor, the key task is to extract Cooper pairs one by one and to spatially separate them into different contacts.

We will analyze theoretically Cooper pairs splitting efficiency, transport mechanisms of Cooper pairs through the system, and possible methods of detection of quantum entangled state using the Bell inequality and entanglement witness approach. It will be proposed an experimental procedure of entanglement detection with use of ferromagnetic detectors, together with discussion of the requirements necessary to be fulfilled by the detectors.