1. **PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan, all in English)**

1.1. Project title: Interaction of an isolated quantum system with single photons

1.2. Project goals:

a) Development of experimental techniques allowing observation of interaction of photon number states with an isolated quantum system.
b) Characterization of materials in terms of optical and microwave fields absorption.
c) Implementation of quantum information protocols based on single photon absorption controlled with external microwave filed.

1.3. Outline

An interaction of an atomic system with a single quanta of electromagnetic filed is a problem, which has already been extensively explored for decades by theoretical means. This basic idea and its followups have positive impact not only on our understanding of fundamental mechanisms of quantum mechanics, but also on practical applications. Quantum microscopy, which has a few flavors, relays on an absorption of a well defined photon number and ability to measure temporal, spectral and spatial characteristics of the emitted fluorescence. Quantum memories are devices which working principle relays on the ability of storage of a single qubits encoded typically in photon's degree of freedom. The basic physical mechanism is based on the ability to control the absorption and emission process in an atomic system. All of them are challenging due to problems with experimental implementations. It has been experimentally demonstrated [Gieysztor2019] that single photon can be absorbed in a medium and the resulting fluorescence can be detected in a controlled laboratory conditions using a typical microscopy setting. This opens up a plethora of new experimental avenues. There are two key components which will be investigated simultaneously , the quantum light with engineered spatial, temporal and photon number characteristics and the materials allowing for effective and efficient iteration. ***Quantum Light.*** We consider a situation in which one photon is used as an illumination in a confocal microscopy setting and the other photon for heralding. The propagation directions of photon pairs can be strongly correlated. It is possible to prepare remotely the spatial mode of the heralded photon (the one used for illumination) by a proper choice of the spatial mode of the measured photon[Pugh2016]. This effect can be used to reduce the size of the illumination mode and in turn increase the spatial resolution of the microscope. Similar effect in the spectral domain, has been predicted [Sedziak 2017] and demonstrated [Sedziak 2019].

Quantum System. Quantum dots attracted lots of attention due the possibility of numerous applications, like single photon sources or, more recently, entangled photon pairs generators. Color centers in diamonds have a potential co be used as quantum memories for photons as quantum information carriers. This kind of atomic-like system embedded in a crystal can also be used as a single photon source, but also as magnetometers. The basic physical principle of such a magnetometers is based on optically detected magnetic resonance. Here a fluorescence intensity is measured as a function of microwave (MW) filed frequency. The MW resonant frequency is around 2.87GHz for nitrogen-vacancy and 50GHz for silicon-vacancy. The goal of the project is an extensive characterization campaign of various materials in terms of the absorption and emission spectrum in optical (340nm-4200nm), and MW (up to 70 GHz), domain from room down to cryogenic temperatures, ca. 4K.

1.4. Work plan: a) **Preliminary study** //6months b) **Search for new materials** *Optical and microwave (MW) absorption characterization.* A sample is placed on a MW antenna connected to a vector signal analyzer sweeping the requency up to 43 GHz. //12 months
Characterization in cryogenic temperatures. Further development can allow to perform the optical and MW characterization in cryogenic temperatures down to 4 K. MW absorption experiments will be performed as well as fluorescence analysis in the presence of MW field. //18 months b) **Absorption of light quanta** *Single-photon absorption.* A custom-made confocal microscope setup is operational. It has been used to perform the proof of principle experiment on illumination of an ensemble of NV center with quantum light. //18 months
Fluorescence analysis in cryostat with MW and single photons. The integration of existing experiemntal setup with cryostat will be necessary. After assembling, alignment and testing a measurement campain will be performed. The potential candidate materials evaluated in the room temperature will be tested in cryostat. //18 months d) **Thesis preparation** //6 months

1.5. Literature:
[Sedziak2017] K. Sedziak, et al, Reducing detection noise of a photon pair in a dispersive medium by controlling its spectral entanglement, Optica, **4**, 84 (2017)
[Sedziak2019] K. Sedziak, et al Remote temporal wavepacket narrowing Sci. Rep., **9,** 3111 [Gieysztor2019] Maria Gieysztor, Marta Misiaszek, Joscelyn van der Veen, Wojciech Gawlik, Fedor Jelezko, Piotr Kolenderski Absorption of a heralded single photon by a nitrogen-vacancy center in diamond, arXiv:1909.05843 [Pugh2016] C. J. Pugh, P. Kolenderski, C. Scarcella, A. Tosi & T. Jennewein Towards correcting atmospheric beam wander via pump beam control in a down conversion process Opt Express, **24**, 20947 (2016)

1.6. Required initial knowledge and skills of the PhD candidate: Strong theoretical and experimental background in quantum optics, preferably with cryogenic experiments.

1.7. Expected development of the PhD candidate's knowledge and skills: The student will get experience with symbolic and numerical algebra systems like Methematica, Python or Matlab, will learn all the skills related to building an optical experimental setup, will gain practical and theoretical knowledge related to quantum information processing.