XXXVIII Cycle Ph.D Course in Physics

First Year Report

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1. Research Activity

My research endeavors center around mitigating quantum noise a limiting factor in the sensitivity gravitational wave detectors. The technique at the core of my research for reducing quantum noise involves injecting squeezed light states into the interferometer. This strategic approach is designed to effectively diminish quantum noise, thereby enhancing the overall performance of gravitational wave detectors. My activities develop both in the Quantum Optics Laboratory in Physics Department and in the Virgo gravitational wave detector situated in Cascina (Pi).

(i) Quantum Noise

Quantum noise arises from vacuum fluctuations entering through the dark port of the detector, manifesting in two interrelated effects: shot noise and radiation pressure noise (RPN). Shot noise, contingent on phase fluctuations of the optical field, predominates at higher frequencies and diminishes with increased laser power. Conversely, RPN, linked to amplitude fluctuations of the optical field, takes precedence at lower frequencies and escalates with higher laser power. The total quantum noise, resulting from the sum of both contributions, limits the entire bandwidth of gravitational wave detectors, from 10 Hz to 10 kHz. The dominance of radiation pressure noise (RPN) at low frequencies necessitates a dual approach: employing phase squeezing at high frequencies and amplitude squeezing at low frequencies. The rotation of the squeezing ellipse with frequency is facilitated by methods such as using a filter cavity, a technique incorporated in ongoing upgrades to Virgo and LIGO, or implementing an Einstein-Podolsky-Rosen (EPR) entangled beams experiment for next-generation gravitational wave interferometers.

(ii) Filter Cavity in Advanced Virgo Plus

In Advanced Virgo Plus (AdV+), the upgrade of Advanced Virgo, a Filter Cavity of approximately 300 meters in length has been installed to implement the Frequency-Dependent-Squeezing (FDS) technique, reducing quantum noise in the entire bandwidth of the gravitational wave detector. The Filter Cavity constitutes a crucial component of the squeezing system in AdV+, and I will be contributing to its control aspects.

(iii) Einstein-Podolsky-Rosen (EPR) Experiment

An alternative strategy involves injecting two Einstein-Podolsky-Rosen (EPR) entangled beams at different frequencies from the interferometer's dark port. The interferometer serves both as a filter cavity and a gravitational wave detector. To experimentally validate this concept, a non-degenerate Optical Parametric Oscillator (OPO) is employed, generating entangled infrared fields with distinct frequencies. Measuring quantum fluctuations on one field induces conditional squeezing on the other, demonstrating the potential of this innovative approach. Upon my arrival in Italy at the end of July 2023, I joined the R&D 1500W EGO-Virgo lab and became actively engaged in various aspects of experimental activities around working on an optical bench. Starting from the current optical setup of the experiment, I contributed to installed and aligned different optical components, focusing particularly on the intricate processes of cavity locking and controls. This alternative technique for reducing quantum noise could be implemented in future gravitational wave detectors, such as the Einstein Telescope. The Einstein Telescope is designed to have significantly improved sensitivity compared to current gravitational-wave detectors. This heightened sensitivity will enable the detection of weaker gravitational-wave signals, providing a more comprehensive understanding of cosmic events and phenomena.

2. My Work

Upon my arrival in Italy at the end of July 2023, I have collaborated on both experiments for quantum noise reduction. Specifically, I have actively contributed to the activities for the EPR experiment at the R&D laboratory on the EGO-Virgo site.I successfully installed different optical components, focusing particularly on the intricate processes of cavity locking and alignment. In particular, I delved into the study of Second Harmonic Generation (SHG), Mach-Zehnder, and Optical Parametric Oscillator (OPO) technologies. My efforts were dedicated to comprehending the intricacies of these optical phenomena and their applications. Additionally, I undertook a comprehensive exploration of Gaussian beams, employing advanced techniques to characterize them. Notably, I utilized a camera to meticulously study and document the properties of Gaussian beams. My experiences in these endeavors not only enhanced my technical skills but also contributed significantly to the ongoing research efforts at the EGO lab. In addition to contributing to the completion of the optical setup, I will be involved in studying and developing controls for the small interferometer of the EPR experiment. Additionally, for the AdV+ experiment, I will contribute to control system activities for the squeezing system.

3. Courses Attended

Upon my arrival in Italy at the end of July 2023, I was unable to attend courses during the first year due to the unavailability of course offerings at that time. Consequently, I have planned to attend all the courses during my second year of Ph.D.