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Einstein-Podolsky-Rosen quantum entanglement for broadband quantum noise reduction in future gravitational-wave detectors

Quantum Noise (QN) limits the sensitivity of ground-based Gravitational Wave (GW) interferometers (ITF) across all the frequency bandwidth (10Hz - 10kHz) 1. Current detectors are designed to achieve broadband QN Reduction (QNR) via frequency-dependent squeezing (FDS) generated in reflection of a 300 m long detuned filter cavity (FC) that is coupled with a frequency-independent squeezing (FIS) source [2, 3, 4]. However, the infrastructure required for the FC is extensive, and this issue is particularly critical for the future generation of GW detectors such as the Einstein Telescope (ET), where multiple km-long FCs are required 5.
Looking ahead to the post-O5 era and the third-generation detectors like ET, more compact, cheaper, and more flexible technologies for broadband QNR, without the need for external FCs, are desirable 5.
A very promising technique uses Einstein-Podolsky-Rosen (EPR) quantum entanglement 6. With this method, two entangled squeezed beams, the signal at the interferometer frequency, and the idler, detuned, are generated from the same source and then injected from the dark port of the ITF. Inside the ITF, the idler beam experiences squeezing ellipse rotation, effectively acting as a filter cavity. EPR squeezing can, in principle, replicate the function of FCs by creating entangled beams whose correlations can be used to reconstruct the desired FDS angle, thus eliminating the need for large, external FCs 6. Hence, this method allows broadband QNR within a considerably more compact setup. To explore the potential of this method, we are developing an experiment in Virgo's R&D squeezing laboratories to measure the effect of EPR-FDS in the audio band region of interest for terrestrial GW detectors 7. This experiment involves 20 members from several Italian universities and related INFN groups (Roma1, Napoli, Perugia, Genova), and South Korean institutions like KASI, Kyung Hee University, and Yonsei University. This talk will overview the current status of the EPR project and highlight its future potential.

References:
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