Fundamental bounds on the precision of 3D localization in coherent and incoherent microscopy

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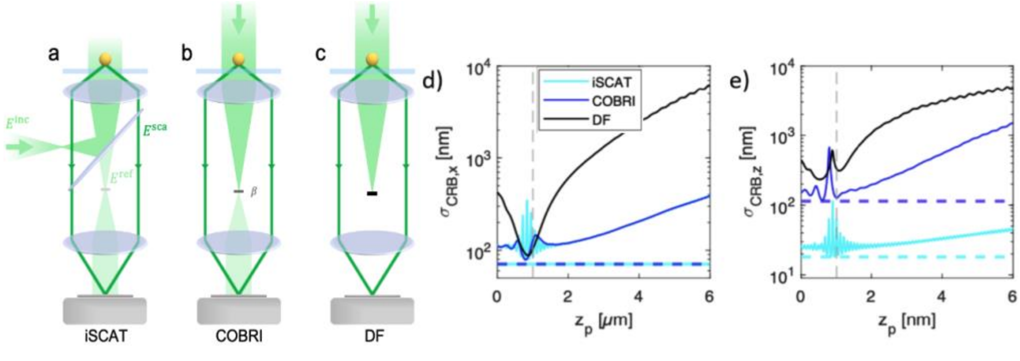
Localization microscopy is now ubiquitous for high-resolution optical imaging. However, the number of observed photons for one position estimation is finite, which limits the achievable resolution. These shot-noise-limited measurements induce fluctuations in the estimated position, that we can quantify with the Cramér-Rao bounds (CRB) on estimation precision.

Scattering-based interferometric imaging has recently been developed for the detection and tracking of single biomolecules in solution. In these techniques, light scattered by a molecule is interfered with a reference to obtain a detectable signal, with different microscope geometries commonly named iSCAT or COBRI.

In this work, we compare the CRB for 3D localization of iSCAT, COBRI, and fluorescence microscopy. We show in particular that the axial sensitivity in iSCAT is greatly increased. To further compare incoherent and coherent imaging techniques, we also derive a quantum CRB to shed light on the information in the quantum state of light itself.



Sketches of the experimental configuration in (a) iSCAT, (b) COBRI and (c) DF microscopy (corresponding to fluorescence microscopy). d) Transverse and (e) axial CRBs for the different schemes as a function of the particle position zp, normalized for one scattered photon detected. The dashed horizontal lines indicate the respective quantum CRBs.