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Fully-automated nanometric optical microscopy for dark matter discovery

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Directional DM search experiments face different challenges especially for the reconstruction of the recoil track and the detector scalability to very large masses while keeping the zero background level. The so-called neutrino floor, where the directionality becomes essential, requires at least a ton-scale detector. These masses are achievable by solid- or liquid-state detectors, but the reconstruction of a recoil track is an incredibly challenging problem: nuclear recoils will have sub-micron lengths. Nuclear emulsions is the only solid-state detector that can provide sub-micrometric resolution scalable to the desired mass. To be competitive with other experiments the entire detector volume must be analyzed in the shortest possible time with the highest achievable resolution. To meet this challenge we are developing the automated sub-micrometric optical microscopy that will incorporate a number of novel techniques and concepts never used before: grain shape analysis, plasmon-resonance analysis, dual plane 3-dimensional readout, multi-camera readout and depth-of-field expansion. Our microscopes are capable of performing completely automated readout of emulsion films with an unprecedented spatial resolution of 10 nm. The advent of the plasmon-resonance analysis enabled overcoming of the optical diffraction limit, which made the reconstruction of recoil tracks with lengths as short as 100 nm possible. Our goal is to push the track reconstruction limit down to 50 nm and our current studies are focused on further improvement of the plasmon analysis technique extending it into the multi-wavelength domain that will provide an additional information on the ionization loss distribution along the particle track and, therefore, will enable the head-tail discrimination of nuclear recoil tracks. We are designing a novel concept for 3-dimensional readout of emulsion films to make the detector equally sensitive in all directions. We are developing multi-camera readout and depth-of-field expansion techniques in order to boost the readout speed and comply with the requirements set by future experiments with ton-scale emulsion detectors.

Primary author: ALEXANDROV, Andrey (NA)

Co-authors: DE LELLIS, Giovanni (NA); TIOUKOV, Valeri (NA)

Presenter: ALEXANDROV, Andrey (NA)

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