Metalenses as Light Concentrators for Liquid Argon Detectors

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Introduction

Metalenses are flat optical components that can replicate the behavior of conventional lenses or exhibit altogether new functionalities impossible to achieve with only standard lenses (Khorasaninejad and Capasso, 2017). Metalenses, being planar, compact, and mass produced have the potential to be used in light detection for noble element detectors. By placing a metalens in front of the Silicon Photomultiplier (SiPM) such that more light is focused onto the SiPM's photosensitive region, the photon collection efficiency can be increased (Villalpando et al., 2020).

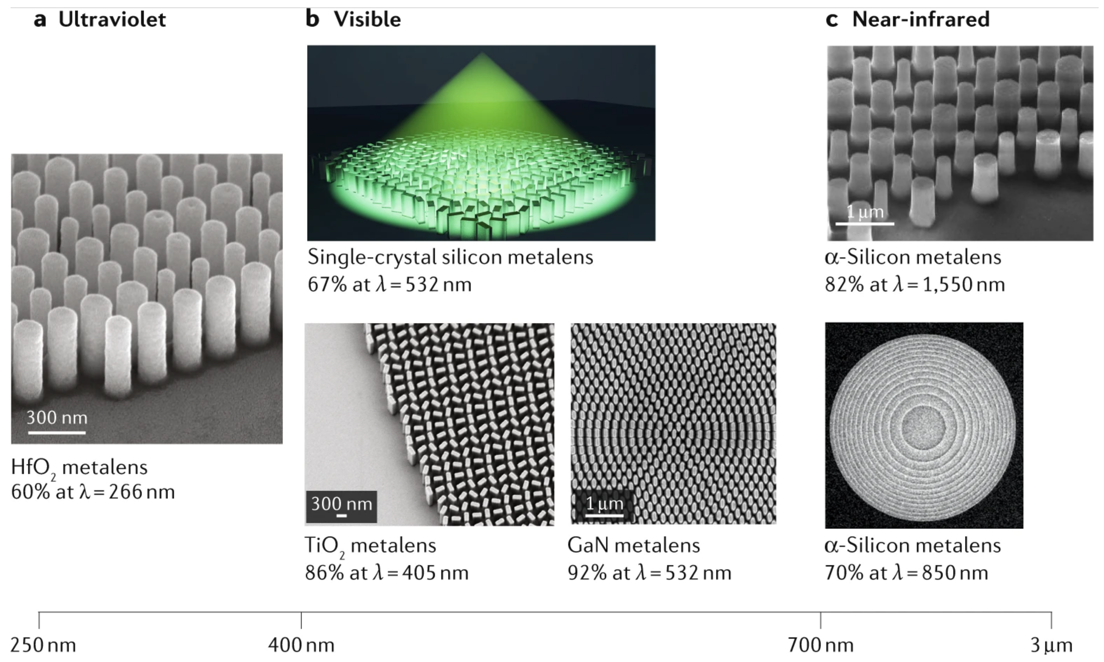


Fig. 1: Metalenses gain their optical properties through these microscopic pillars pictured above. They work by locally phase-shifting the incident light using sub-wavelength optical scatterers. (Chen, Zhu, and Capasso, 2020)

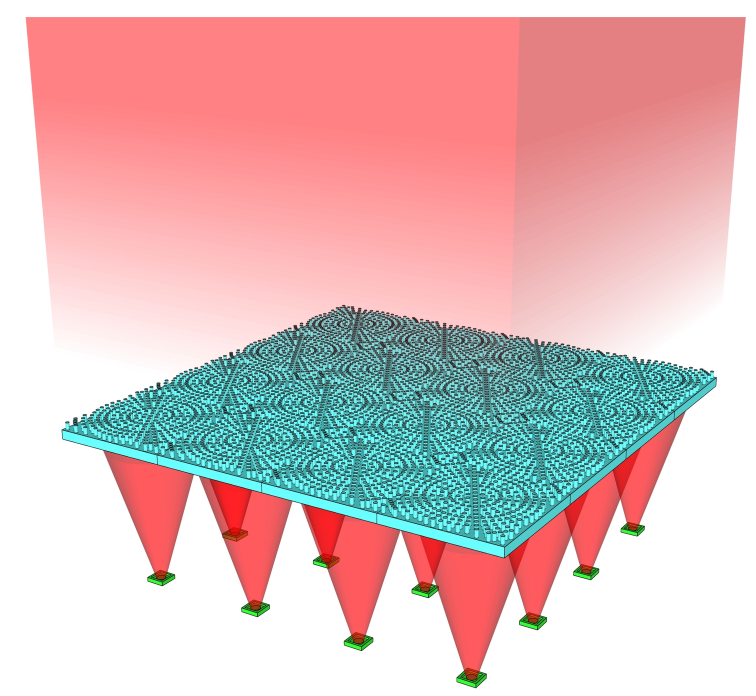
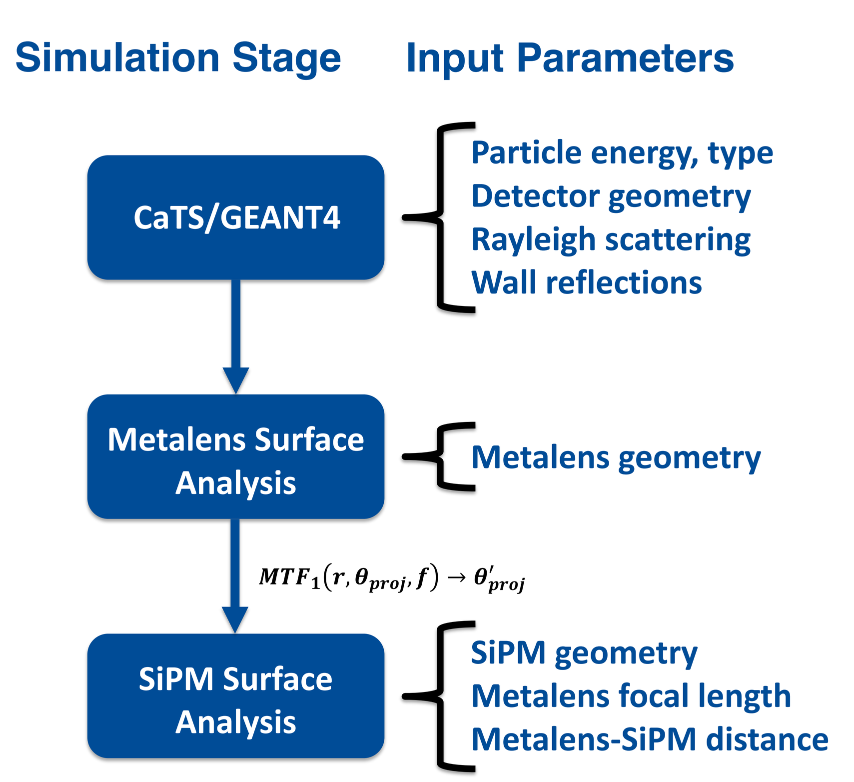


Fig. 2: A model metalens-SiPM setup. Scintillation light (red) shines on the 4x4 metalens array (blue) and is focused down onto the nearby SiPM array (green). Note the small size of the SiPMs in relation to the metalenses. Not to scale. Generated with SketchUp.

Purpose & Outline



This project seeks to develop a simulation tool to explore the light distributions on the metalens and SiPM planes. The code is written in Python and has the capability of writing ROOT histogram files using PyROOT. The program interfaces with GEANT4/CaTS in order to simulate the photon production and light propagation through the LAr volume. Tweaking the different input parameters (left) allows the user to easily evaluate and compare multiple different setups. By toggling different parts of the simulation (e.g., Rayleigh scattering), we can explore how each component changes the final result.

Results

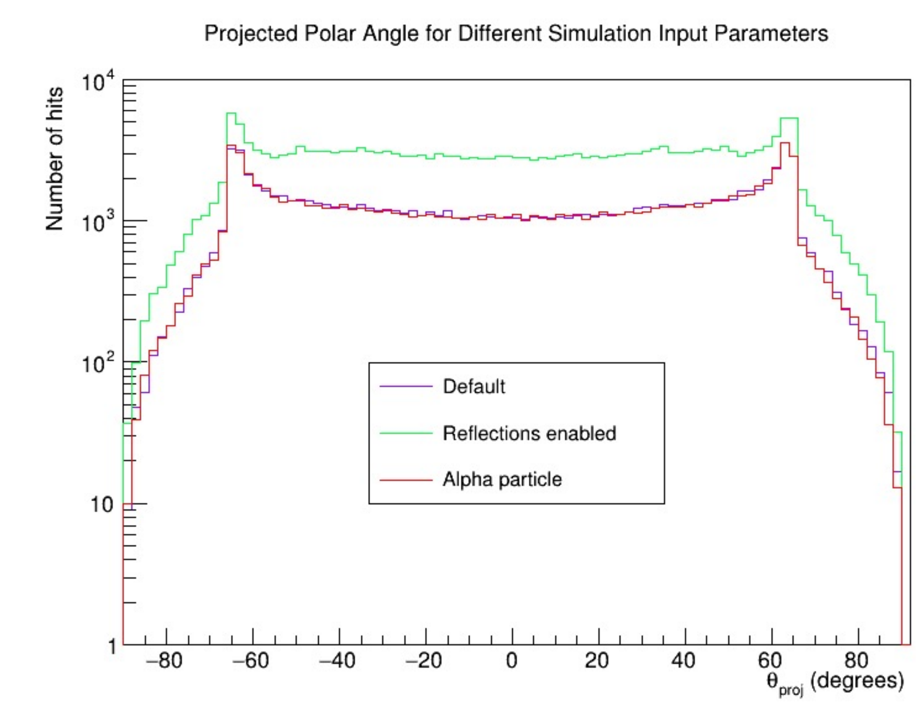
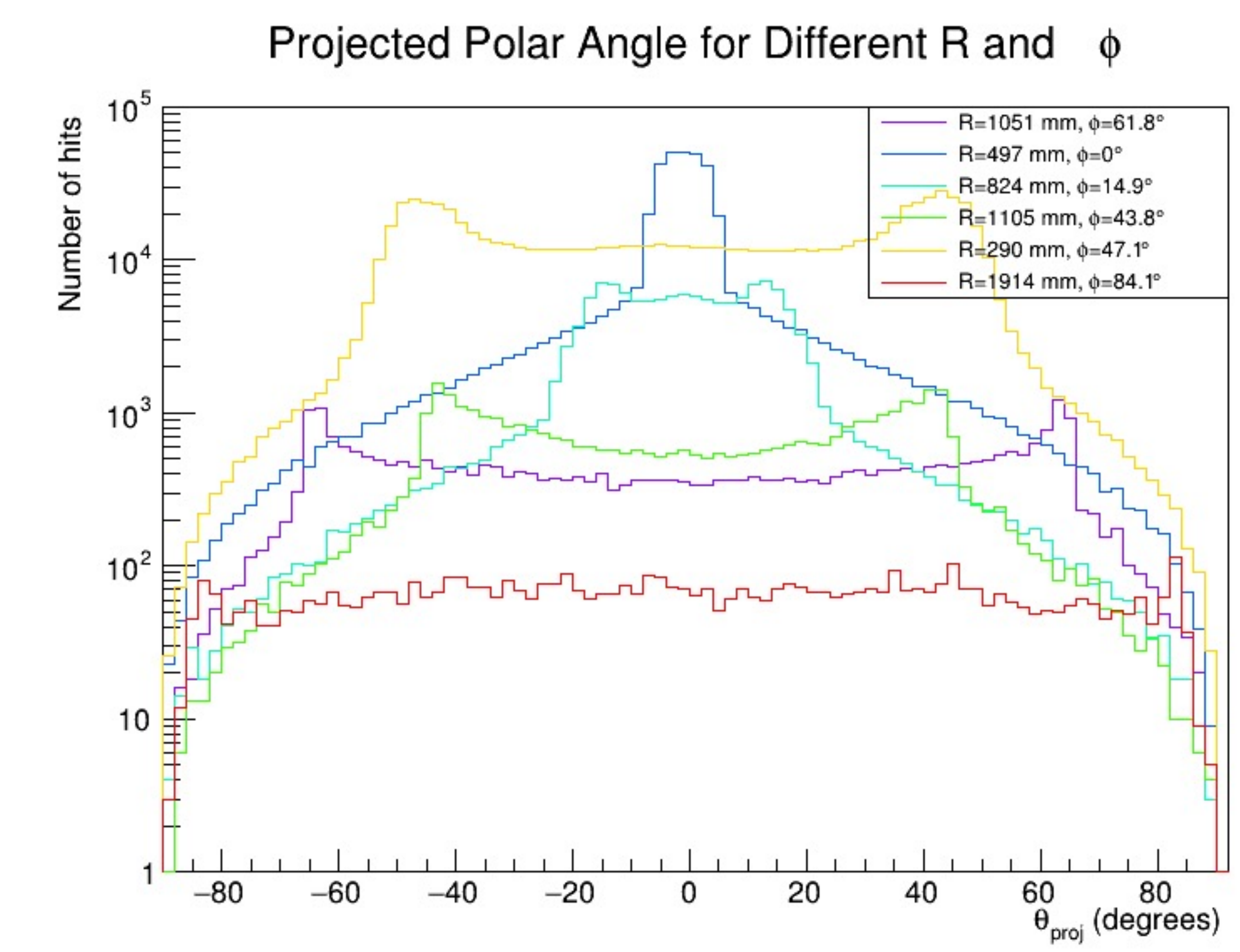


Fig. 3: Photons that hit a metalens after being reflected by a wall in the LAr volume increased the noise surrounding the direct photons in all angular distributions. Switching from 2.5 MeV electrons to 2.5 MeV α particles does not significantly change the distribution.

We observed that reflections from the walls significantly change the incident light distribution on the metalenses. The angle and distance of the event in LAr relative to the metalens region has a heightened significance compared to the bare-SiPM setup. To measure this, we define θ_{proj} to be the "projected polar" angle. It is formed by the projection of the photon's direction vector onto the plane that runs from the metalens center to the photon's impact position. The angle of this vector with respect to the metalens normal vector is θ_{proj}.



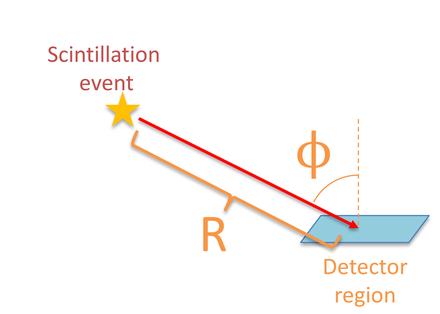


Fig. 4: The incident light from six separate events is displayed above. The distance between the detector and the event (R) generally increases or decreases the net photons collected by the detector. Changes in the angle between the detector region and event (ϕ) also change the aggregate photon count, but also has a large effect on the shape of the θ_{proj} distribution.

Conclusions

The Metalens Transfer Function (MTF) maps θ_{proj} and the radial position r to a new angle θ'_{proj} to simulate the passage of a photon through a metalens. This program provides insight into how this angular distribution changes in response to many input parameters. For the first time, photons can be propagated from their initial creation in LAr, through a metalens, and onto a SiPM to be analyzed.

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