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Geant4 simulation of the ABALONE photosensor

G. Pieramico(1)(2)(*), R. Biondi(2), V. D'Andrea(2)(3), A. D. Ferella(2)(3) and J. Mahlstedt(4)

(1) *Dipartimento di Fisica, Università di Roma "La Sapienza" - 00185 Roma, Italy*
(2) *INFN, Laboratori Nazionali del Gran Sasso - 67100 L'Aquila (AQ), Italy*
(3) *Dipartimento di Scienze Fisiche e Chimiche, Università degli studi dell'Aquila 67100 Coppito (AQ), Italy*
(4) *Oskar Klein Centre, Department of Physics, Stockholm University SE-106 91 Stockholm, Sweden*

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Summary. — The ABALONE is a new type of photosensor produced by PhotonLab, Inc. with cost effective mass production, robustness and high performance. This modern technology provides sensitivity to visible and UV light, exceptional radio-purity and excellent detection performance in terms of intrinsic gain, afterpulsing rate, timing resolution and single-photon sensitivity. The ABALONE is based on the acceleration of photoelectrons in vacuum. These are generated in a traditional photocathode and guided towards a window of scintillating material. The resulting scintillation light can be read from the outside via a silicon photomultiplier (SiPM). The device has been proposed as a possible candidate for the DARWIN experiment. We performed the complete simulation of the detector, mapped the electrostatic field within the vacuum of the sensor and studied its possible optimization.

1. – Description

The ABALONE Photosensor [1] aims to detect light from outside, intensify it and measure it as an electrical signal at the end of the process. The simple ABALONE Photosensor design comprises only three industrially pre-fabricated glass components [2]. These three glass pieces are the Dome, the Base Plate and the Windowlet, see fig. 1. The ABALONE Photosensor receives photons through the entire glass Dome. A photon arriving on the Dome, due to the photoelectric effect, interacting with the photocathode, is converted into a photoelectron. The latter is released into the vacuum cavity and accelerated towards the Windowlet. The photoelectron is accelerated by the electric

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(*) Corresponding author.

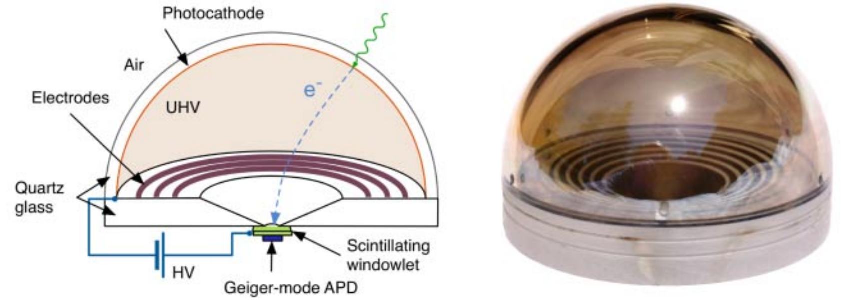

Fig. 1. – The ABALONE Photosensor schematics and a prototype developed for the IceCube extension project [2].

field created inside the device, being the Base Plate connected to an external high voltage generator. The photoelectron is then focused into the region of the Windowlet exposed to the vacuum and finally into the hole of the Base Plate.

After passing through the hole of the Base Plate and before entering in the scintillator, the photoelectron first penetrates through the thin chromium and gold layer and suffers a little energy loss. Once inside the scintillator and assuming the photoelectron does not eventually back-scatter, the photoelectron looses all of its energy, generating secondary photons. The goal of the study presented here is to characterize the ABALONE Photosensor through the full simulation of the device which has been among the possible candidates for the DARWIN experiment [3]. The simulation reconstructs the ABALONE geometry in all its parts, the trajectory of the particles from the Dome to the Windowlet and the light response of the NUV-HD SiPM [4] used in our experimental setup. COMSOL Multiphysics 5.4 [5] and GEANT4 [6] are the two toolkits used for this analysis.

2. – Simulation of the ABALONE electrical field

COMSOL Multiphysics allows us to simulate the geometry of the ABALONE. COMSOL Multiphysics divides the model into several branches: geometry, materials, physics, study, results. Through the physics of the software we are able to study the electric potential and electron trajectories from the Dome to the Windowlet. The electric potential passes through the outside of the Base Plate and into the photocathode, while the Windowlet is at ground state. This simulation is done with the photocathode at 25 kV that is the electric potential fixed to the highest practical setting. The results are shown in fig. 2.

3. – Analysis of the photoelectrons trajectories

The GEANT4 Simulation reconstructs the geometry of the photosensor. It calculates the trajectory of electrons from the photocathode to the scintillation Windowlet.

As output it provides the particle trajectories, the energy deposited on the scintillator coating and the light response of the SiPM. We present the simulation at 25 kV by varying the starting angle of the photoelectron with respect to the vertical. Figure 3 shows 1 photoelectron at 0°, 75°, 85° with respect to vertical.

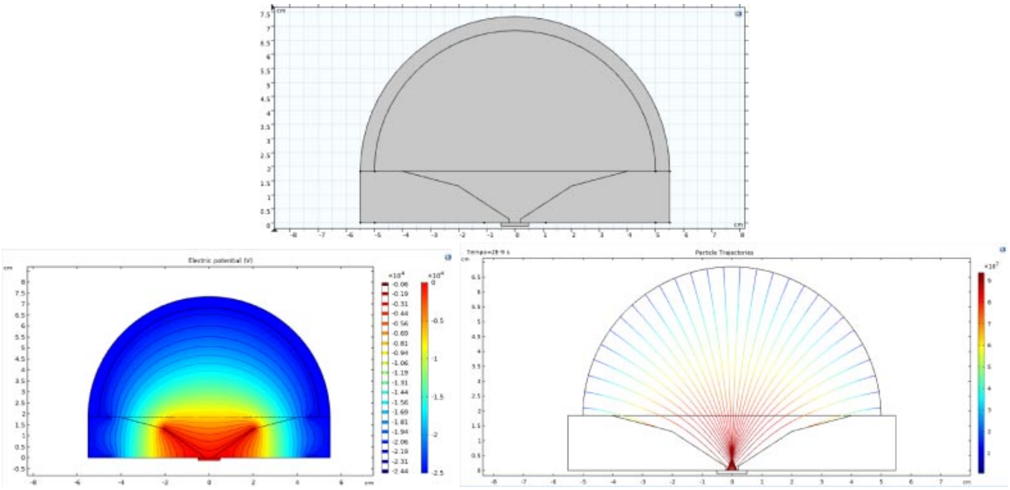

Fig. 2. – Top: ABALONE Geometry in 2D, Bottom: electric potential (left) and electron traces (right) at 25 kV.

The trajectory analysis of photoelectrons allowed us to classify them in the following categories: Straight Electrons, which are those that are detected directly, Returning Electrons those that are scattered back in the vacuum and end up again in the Windowlet, Non-Returning Back Electrons (NRBE) those scattered back into the Base Plate and do not return to the Windowlet and Undetected Electrons the electrons that are not detected.

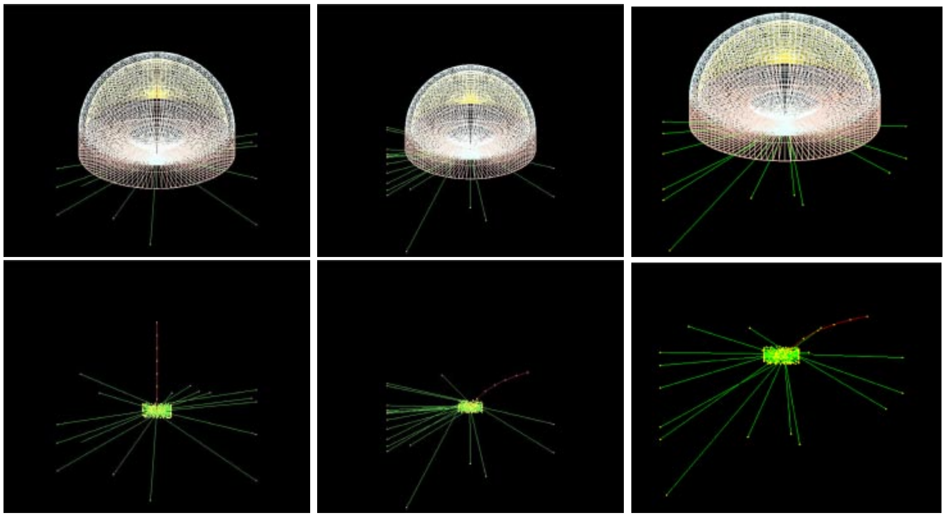

Fig. 3. – From the left to right: simulation of a photoelectron at 0°, 75°, 85° with full geometry (top), simulation of a photoelectron at 0°, 75°, 85° only with the SiPM (bottom) at 25 kV.

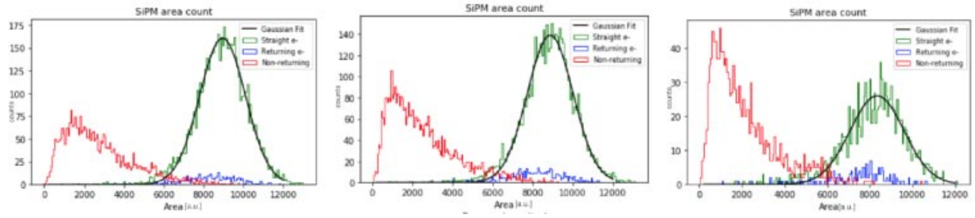

Fig. 4. – From the left to right: Portion of Straight, Returning and Non-Returning Back Electrons at 0°, 75°, 85°.

The analysis is performed at different injection angles for 1 photoelectron from 0° to 85° with respect to vertical direction. The plots in fig. 4 show 1 photoelectron at 0°, 75°, 85°, respectively from the left to the right.

Thanks to this study we calculated the portion of the different classes of photoelectrons as function of the injection angle. Below 75° the fraction of straight, returning and non returning electrons has a costant trend, most of the electrons arrive in the hole of the scintillation Windowlet and a small fraction of them are non returning back electrons. Above 75° the fraction of undetected electrons grows. This growth is due to the geometry and the electric field inside the photosensor. At very large angles we have a greater number of undetected electrons. Figure 5 shows this result.

4. – Conclusions

We reported the simulation of the ABALONE Photosensor at 25 kV by varying the photoelectron angle, showing the trend is constant up to 75°, while there is a growth of undetected electrons at higher angles. Our goal is to characterize the photosensor and compare simulations with experimental data. Our future program will be a fixed angle simulation analysis, 0 degrees, varying the voltage from 0 kV to 25 kV, reconstructing our experimental setup. Next we would like to modify the scintillator to evaluate if there is an improvement in the Non-Returning Back Electrons percentage and thus a growth in the photosensor gain.

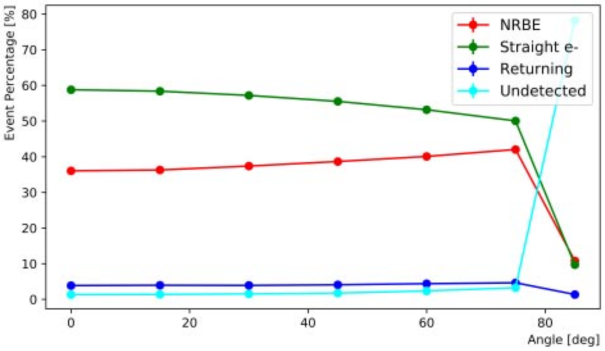

Fig. 5. – Fraction of different classes of photoelectrons as function of the injection angle.

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