The Optical Simulation Model of the DarkSide-20k Veto Detector

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DarkSide-20k

- DarkSide-20k (DS-20k) is a dual-phase rare-event search experiment dedicated to finding the signals of long-theorised dark matter particles.
- The experiment will be located at LNGS under Gran Sasso with a 3800 m.w.e.
- In order to find this signal, DS-20k employs liquid argon (LAr) as the detector medium, and uses ionisation and light signals to detect the particle interactions.
- LAr is used in the inner chamber (~50 tons) instrumented with SiPMs, enclosed in an active LAr veto enclosed in a passive LAr shield tank
- The veto of the DS-20k is crucial for detecting neutrons, and the setup includes both an inner and an outer veto

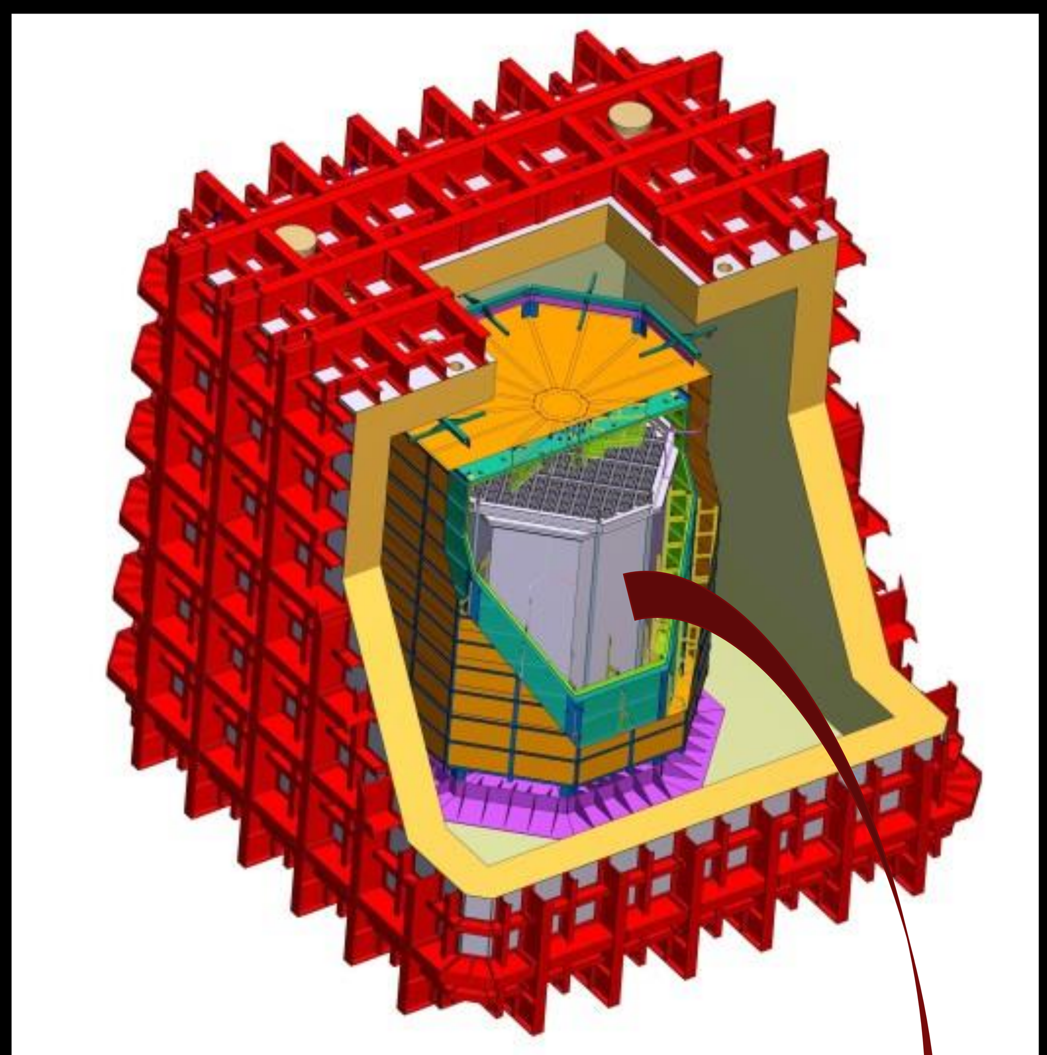

Figure 1: (Top) DarkSide-20k inside a cryostat [1] and (Bottom) layers of the veto made up of LAr, ESR and PEN

Optical Simulations of DS-20k

- In order to test the performance and make necessary changes before finalising the design of the DS-20k detector, a detailed Geant4 simulations code was constructed.
- The simulation code includes a detailed representation of the DS-20k geometry, as well as the physics processes that are expected to occur.
- One of the crucial parts of the physics of DS-20k veto is the optics.
- Dark matter particles are expected to hit argon atoms which will excite them, resulting in emission of light due to de-excitation in the vacuum ultraviolet (VUV) part of the electromagnetic spectrum.
- Since SiPMs are not sensitive enough for VUV light, wavelength-shifter (WLS) materials that can shift the wavelength of the VUV light into optical light are used
- Inside the Time Projection Chamber (TPC), tetraphenyl-butadiene (TPB) powder is used as a WLS, whereas in the veto, polyethylene naphthalate (PEN) films are used.
- Walls lined with Enhanced Specular Reflectors (ESR) collect visible light to SiPMs
- Due to the thin film nature of PEN and the place of the veto in the experiment, the veto optics is crucial to implement in a great detail.
- The parameters that were used to develop the optical simulations are shown in Table 1 where they are divided into two categories: WLS properties of PEN and the properties of the veto setup

WLS Properties of PEN		Properties of the Veto Setup	
Parameters	Value	Parameters	Value
Emission time	20 ns [2]	Reflectivity of the walls (ESR)	Figure 2 (b) (black)
Wavelength shifting efficiency	47.2 % of TPB [4]	Reflectivity of the detector material (SiPM)	Figure 2 (b) (green)
Absorption length	1 cm (visible) [6]	PDE	Figure 2 (c)
Rayleigh scattering length	150 μm (visible) *	LAr absorption length	100 m for both UV and visible *
Refractive indices	1.75 (UV and visible)		
Emission spectrum	Figure 2 (a)		

Table 1: Table showing the two sets of properties used in the optical simulations of the DS-20k veto
* assumed

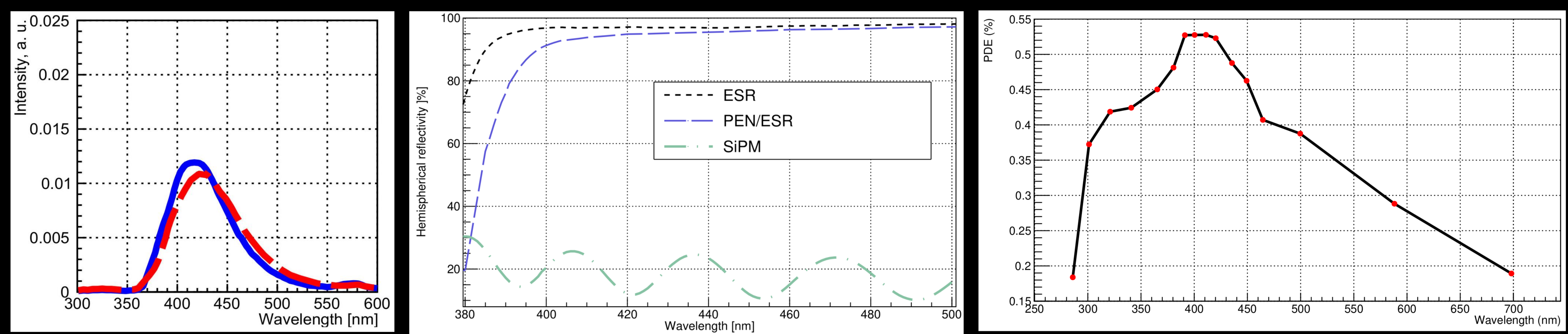

Figure 2: Set of figures showing (Left) emission spectra of PEN at room temperature (red) and at cryogenic temperature (blue) [3], (Middle) reflectivity percentages of ESR (black), PEN air-coupled to ESR (blue) and SiPM (green) [4], (Right) photon detection efficiency (PDE) percentage [1]

Results of DS-20k Simulations

- Optical properties in Table 1 were added to the veto simulations of DS-20k, and their individual effects on the light yield (LY) were investigated.
- To understand whether the results are correct, a comparison with a simple analytical model was made [5]:

$$LY = 40\ [\mathrm{ph/keV}] \cdot PDE\ [\mathrm{pe/ph}] \cdot WLSE \cdot \frac{F_{sens} \cdot FF \cdot (1 - R_{sens})}{1 - (F_{sens} \cdot R_{sens} + (1 - F_{sens}) \cdot R_{wall})}$$

- This model takes into account the wall reflectivity (R_{wall}), the SiPM coverage fraction (F_{sens}), the SiPM reflectivity (R_{sens}), the SiPM PDE (*PDE*), fill factor (*FF*) and the wavelength shifting efficiency (*WLSE*)
- The Monte Carlo simulation validated against the analytical model, which can be seen on Figure 3, confirmed the suitability of the PEN WLS, despite its lower wavelength shifting efficiency, for DS-20k veto in place of TPB

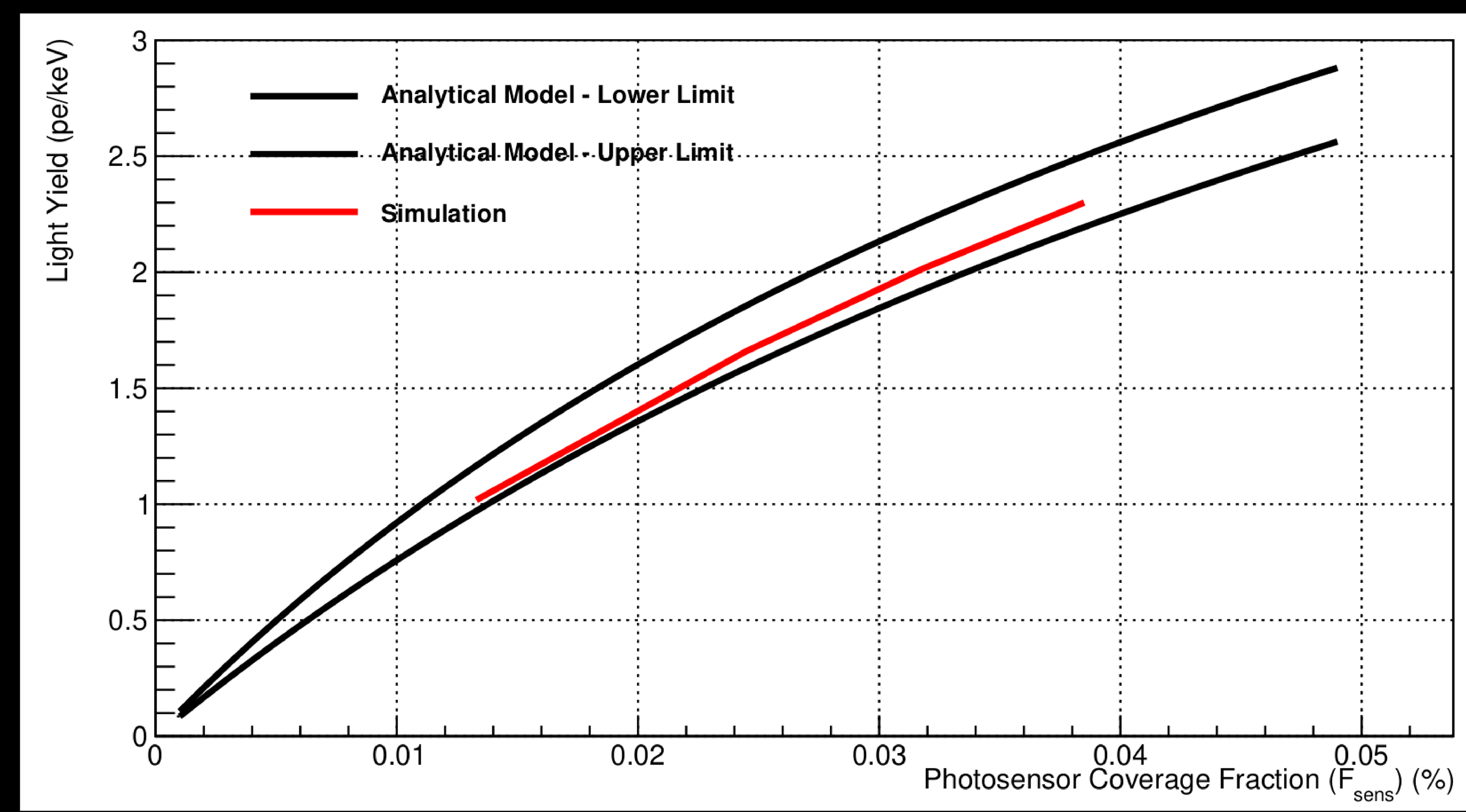

Figure 3: Light yield output of the veto simulations (red) with respect to different configurations of the photosensor (SiPM) coverage fraction compared to the analytical model (black) according to [5]

References

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6) Y. Efremenko, L. Fajt, M. Febbraro et al., JINST 14(07), P07006 (2019). DOI 10.1088/1748-0221/14/-7/p07006

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