

# Liquid Argon optical properties to be used in Geant4 and Opticks Simulations

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**Abstract.** In Geant4 and Opticks optical properties like e.g. the materials refractive index are inputs that have to be provided. In this paper we collect the optical properties relevant for liquid Argon TPC's.

## 1. Introduction

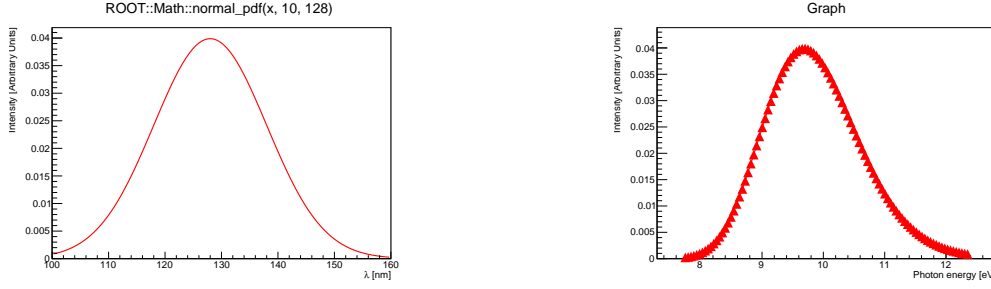
In Geant4 and Opticks optical properties like e.g. the materials refractive index are inputs that have to be provided when the detector is constructed. In this article we briefly describe the physical processes relevant to the production, transport and detection of optical photons in liquid Argon. We collect the values and parameterizations of optical properties relevant for liquid Argon TPC's. We provide scripts that plot this quantities and that convert this values into a gdmf description that can be directly used in the Geant4 Detector description. All values are summarized in the file `material.xml` which can be found in the github repository [6]. Usually quantities are given as a function of photon wavelength but Geant4 requires the photon energy. The motion of the charged particles liberates charge from the surrounding argon (ionization) and produces light (scintillation)

$$E_{\gamma}(eV) = \frac{hc}{\lambda_{\gamma}10^{-9}} \quad (1)$$

with:

speed of light:  $c = 299792458 m/sec$

Planck constant:  $h = 4.13566743 \times 10^{-15} eV/sec$



**Figure 1.** Scintillation emission spectrum.

## 2. Light production

### 2.1. Scintillation Properties of liquid Argon

Efficient scintillator with typical Light yields in the order of a few 10,000's of photons per  $MeV$  deposited (depends on E field, particle type and purity) (SCINTILLATIONYIELD: 50000/ $MeV$  when no electric field present) Scintillation yield is E-field and particle dependent. For a proton: 24,000 photons /  $MeV$ ,  $E = 500$  V / cm 40,000 photons /  $MeV$ ,  $E = 0$  V / cm

Liquid argon produces scintillation light via two distinct scintillation mechanisms, each of which has a different characteristic time constant

Property/Geant4 keyword	value
yield/SCINTILLATIONYIELD	50000 $\gamma/s/MeV$ (no electric field)
Wavelength of emission	128nm ( $FWHM = 10nm$ )
fast component/SCINTILLATIONTIMECONSTANT1	6ns
fast fraction/SCINTILLATIONYIELD1	0.75
slow component/SCINTILLATIONTIMECONSTANT2	1500ns
slow fraction/SCINTILLATIONYIELD2	0.25
RESOLUTIONSCALE	1

**Table 1.** Scintillation Properties of liquid Argon.

Scintillation Quenching, Birks

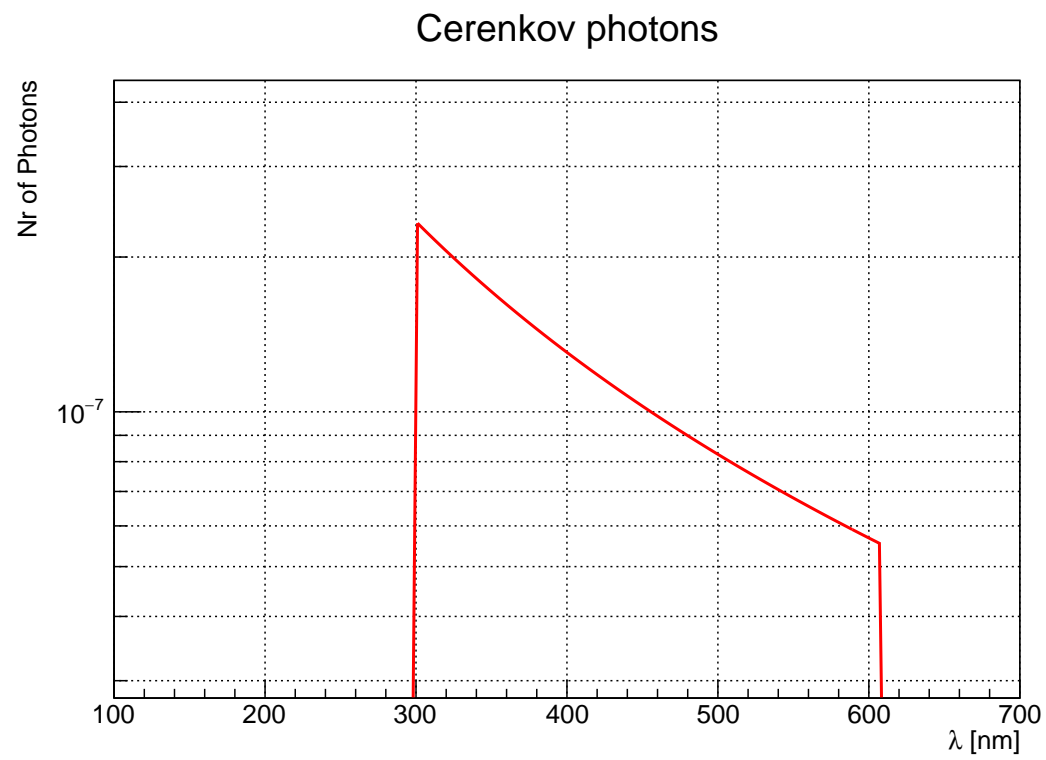
### 2.2. Cerenkov spectrum and Yield

A charged particle radiates if its speed is greater than the local phase speed of light  $v_p$  In Geant4 the process is not contributing to energy loss.

the charged particle travels in a medium with speed  $v_p$  such that  $\frac{c}{n} < v_p < c$ .

$$\cos(\theta_C) = \frac{1}{n\beta} \quad (2)$$

$$\frac{d^2N}{dEdx} = \frac{2\pi\alpha z^2}{\lambda^2} \left( 1 - \frac{1}{(\beta^2 n^2(\lambda))} \right) \quad (3)$$



**Figure 2.** Cerenkov spectrum

### 3. Light propagation

#### 3.1. Refraction Index and group velocity

Refraction Index:  $n = 1.358 \pm 0.003$  at  $128nm$  [9]. ( compared to  $n = 1.45 \pm 0.07$  [8]) Group velocity:  $\frac{1}{v_g} = 7.46 \pm 0.08 ns/m$  at  $128nm$

$$n^2 = a_0 + \frac{a_{UV}\lambda^2}{\lambda^2 - \lambda_{UV}^2} + \frac{a_{IR}\lambda^2}{\lambda^2 - \lambda_{IR}^2}. \quad (4)$$

Scintillation $\lambda$ (nm)	UV Resonance $\lambda$ (nm)	IR Resonance $\lambda$ (nm)
128	106.6	908.3

**Table 2.** blabla bla.

$T(K)$	$a_0$	$a_{UV}$	$a_{IR}$
83.81	$1.24 \pm 0.09$	$0.27 \pm 0.09$	$0.00047 \pm 0.007$
90	$1.26 \pm 0.09$	$0.23 \pm 0.09$	$0.0023 \pm 0.007$

**Table 3.** Sellmeier coefficients

where the parameters  $a_0$  ,  $a_{UV}$  and  $a_{IR}$  known as Sellmeier coefficients have to be determined experimentally.

The relation between group velocity and the refraction index is given by:

$$v_g(\lambda) = \frac{c}{n - \lambda \frac{\partial n}{\partial \lambda}} \quad (5)$$

#### 3.2. Absorption length

Argon is highly transparent to its own scintillation light. (ABSLENGTH) > 1.1m (ArXiv:1511.07725)

#### 3.3. Rayleigh Scattering length

Rayleigh scattering length (RAYLEIGH). In the literature one can find the following values at  $128nm$ : 90 cm [9] and  $55 \pm 5cm$  [8].

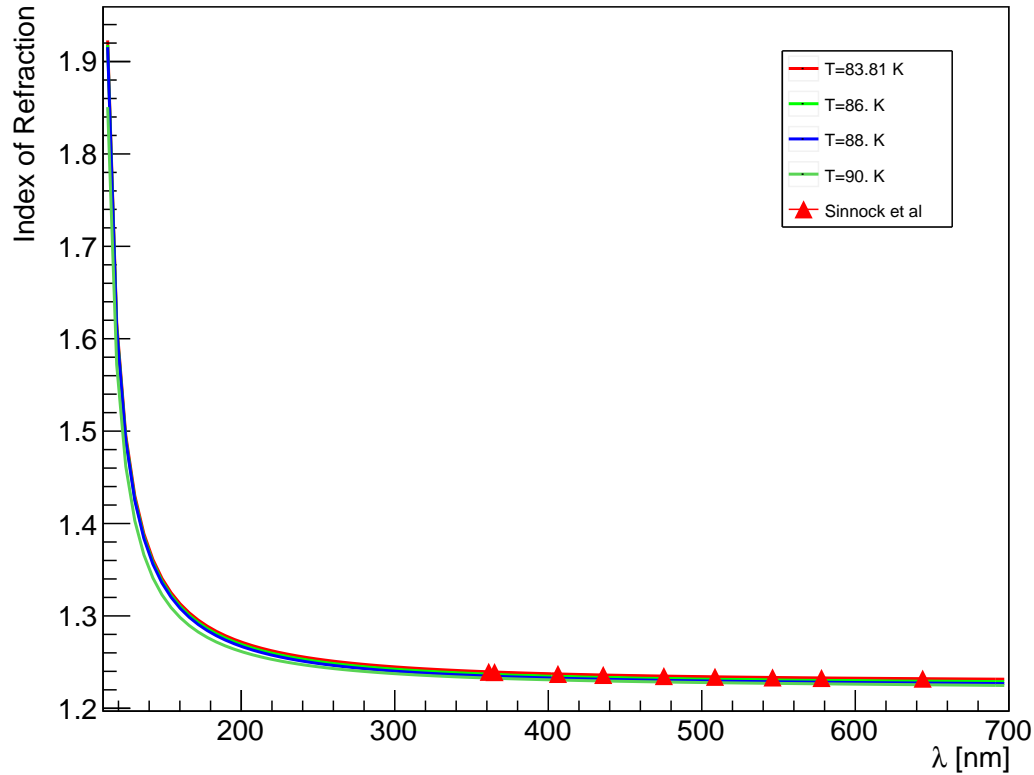
$$l^{-1} = \frac{16\pi^3}{6\lambda^4} \left[ kT\rho^2 k_T \left( \frac{(n^2 - 1)(n^2 + 2)}{3} \right)^2 \right] \quad (6)$$

with:

speed of light:  $c = 299792458m/sec$

Planck constant:  $h = 4.13566743 \times 10^{-15}eV/sec$

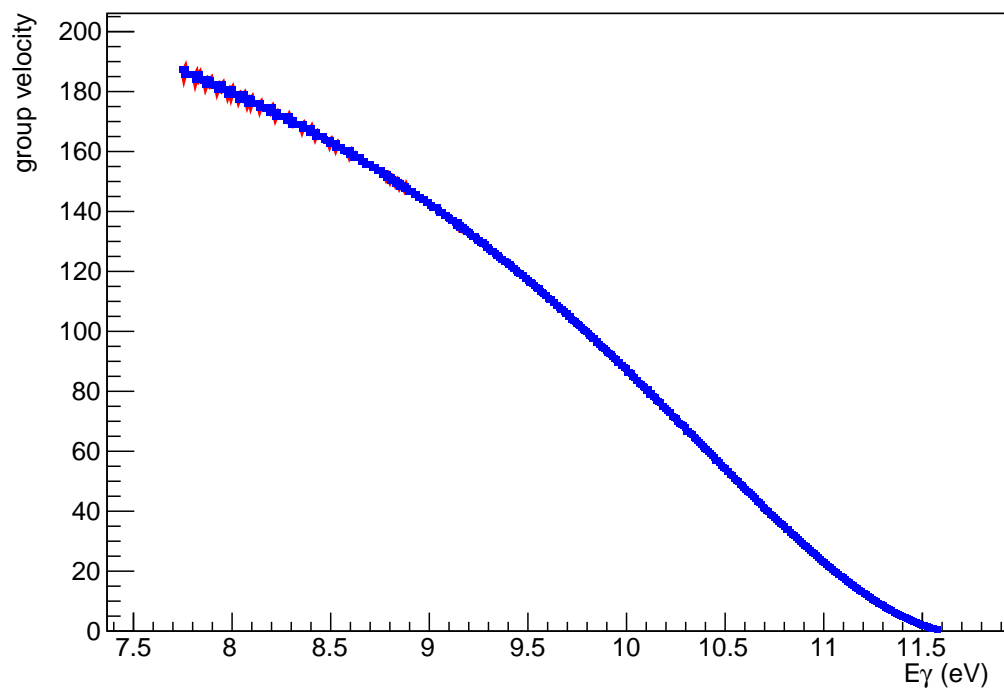
T=83.81 K



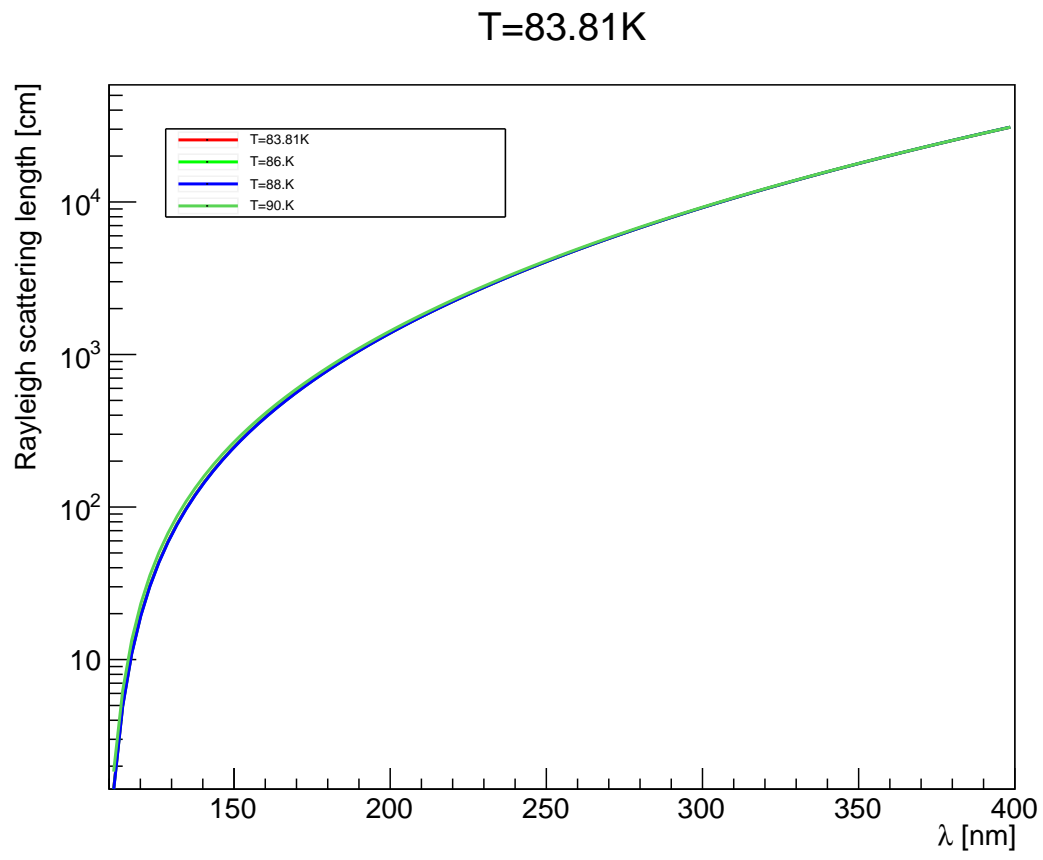
**Figure 3.** refraction index

### 3.4. reflection

- $n$  which waves arriving at the interface (boundary) from one medium to another The Fresnel equations (or Fresnel coefficients) describe the reflection and transmission of light (or electromagnetic radiation in general) when incident on an interface between different optical media.(boundary between liquid Ar and wls, wls and photodetector.)
- Specular reflection, or regular reflection, is the mirror-like reflection of waves, such as light, from a surface.[1] The law of reflection states that a reflected ray of light emerges from the reflecting surface at the same angle to the surface normal as the incident ray, but on the opposing side of the surface normal in the plane formed by the incident and reflected rays. (boundary between liquid Argon and metal walls of cryogenic vessel)



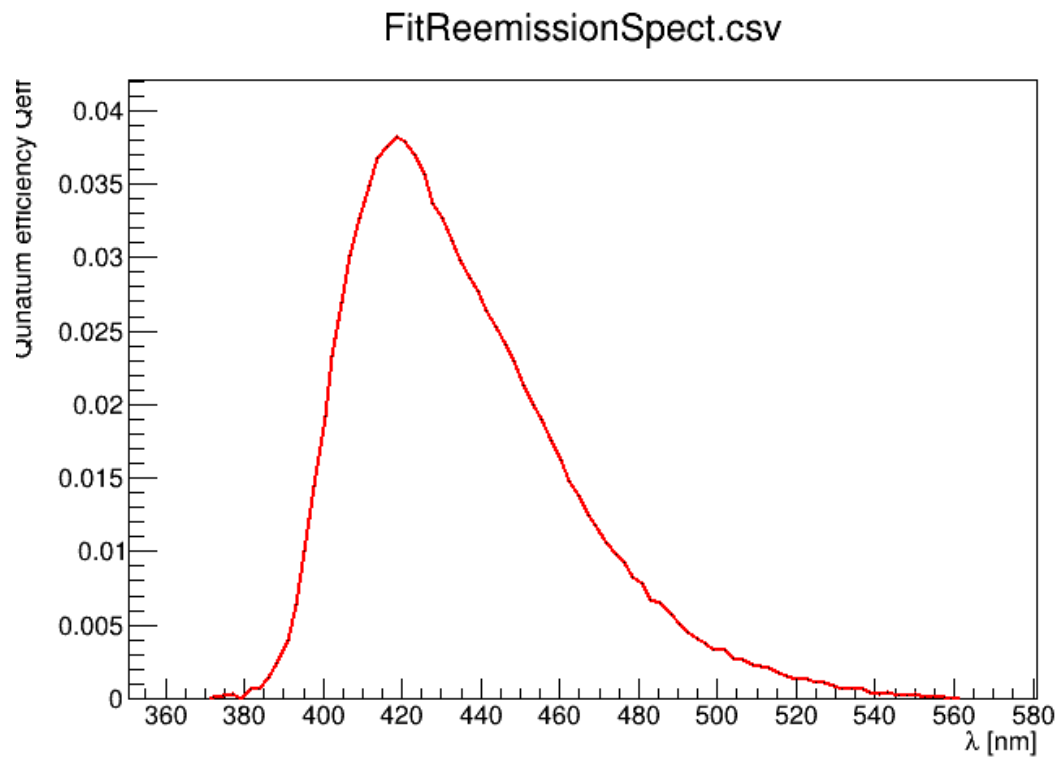
**Figure 4.** group velocity



**Figure 5.** rayleigh scattering length.

#### 4. Photon Detection

4.1. *Quantum efficiency and absorption length of the tetraphenyl butadiene wave length shifter*  
[7]



**Figure 6.** wave length spectrum extracted form [7].

#### 5. Conclusions and Outlook



## References

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