Setup for an in-situ measurement of the total light extinction of Liquid Argon in GERDA

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GERDA

LAr Instrumentation for Phase II

LAr veto

- $\beta\beta$-events do not trigger scintillation light
- Background events in the ROI typically have excess energy $\rightarrow$ deposited in the LAr
- Anti-coincidence veto on Ge-detectors also suppresses background

Hybrid design

- Combination of PMTs and scintillation fibers for maximized veto efficiency
- PMTs at top and bottom
- Upper and lower part with mesh of copper coated with Tetratex & WLS
- Middle part with mesh of scintillation fibers & WLS

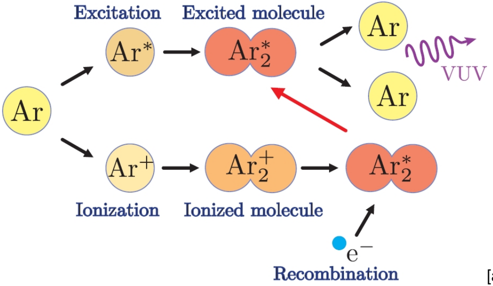
Motivation for the light extinction measurement

- Light extinction is the parameter with the largest uncertainty for the veto efficiency
- Photoelectron yield depends directly on the amount of light that reaches the instrumentation
- Light extinction is highly dependent on the specific composition (amount of impurities)
- Ex-situ measurements exist
  $\rightarrow$ not accurate for the case of GERDA because of unknown impurity content in the argon

Further gain

- Investigation of LAr energy response
  $\rightarrow$ improvement of LAr veto efficiency
- Determine effective active volume of LAr
- Light extinction + triplet lifetime measurement
  $\rightarrow$ rough estimate of LAr purity

LAr Scintillation Mechanism

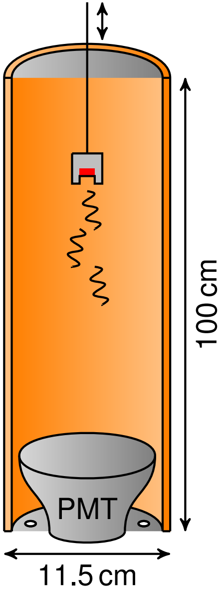


[arXiv:0708.2621v1]

- Ionizing radiation leads to excited or ionized argon atoms
  $\rightarrow$ Forming molecules with ground state argon atoms
- Ar_2^+ recombine with free electrons into excited states
- Excited states are created in:
  - singlets (allowed, $\tau \sim 6\,\text{ns}$)
  - triplets (forbidden, $\tau \sim 1.5\,\mu\text{s}$)

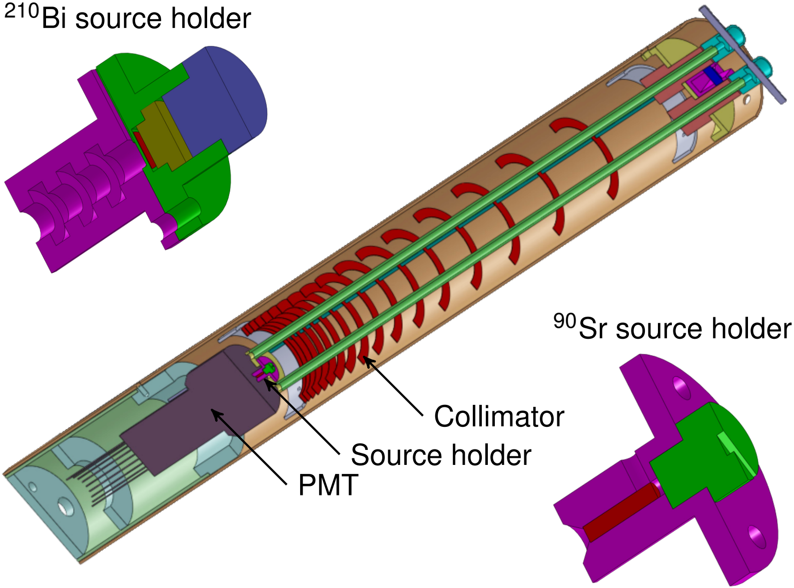
  $\rightarrow$ decay under emission of photons, $\lambda = 128\,\text{nm}$
- Contaminations lead to reduction of triplet lifetime (mostly due to quenching)

Concept of the setup



- Steel cylinder → reduce weight & costs
- 3" PMT coated with WLS
  → 9361FLB from ET Enterprises
- Encapsulated source
- Moveable source holder
- Source holder of steel
- Solid angle correction for each measuring point dependent on distance between PMT and source
- Light reflections lead to an overestimated attenuation length
  → small source window, collimators

Setup and source holder design



The source

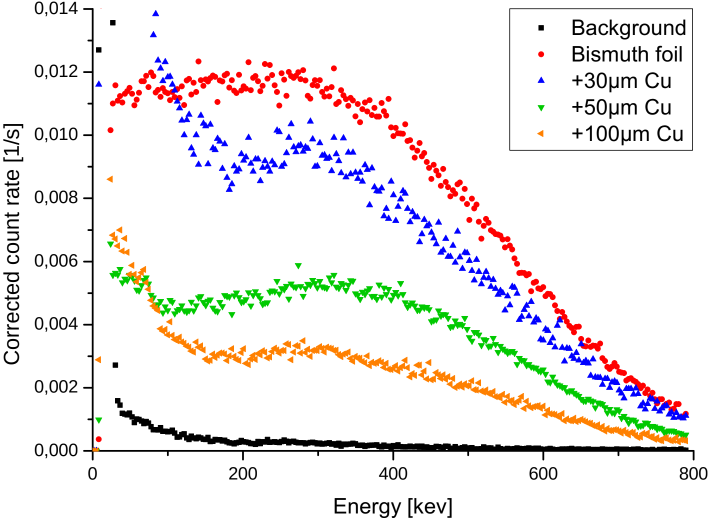
- Major source of uncertainty:
  distance between PMT and source
- Energy deposition as large and point-like as possible
  $\rightarrow$ no γ-source
- Encapsulated $\rightarrow$ no α-source
- Most promising: pure β-source
- High Q-value to get as much scintillation light as possible
  (nominal 40 photons per keV $\rightarrow$ expected to be lower)
- Half life about several days $\rightarrow$ measuring at a stable point
  $\rightarrow$ parasitic isotopes with short lives can fade away
- Favourable: in-house produced ^{210}Bi, ^{90}Sr from LNGS

	^{210}Bi	^{90}Sr
Q-value	1.1 MeV	2.3 MeV (^{90}Y)
Half life	5 d	28.6 yr
Activity	< 50 kBq	7 kBq

[Values from http://ie.lbl.gov/toi/]

Results of the beta spectrometry

- 250 µm, 99.999% ^{209}Bi foil
- $^{209}Bi(n,\gamma)^{210}Bi$ activation with AKR II, TUD



Simulation

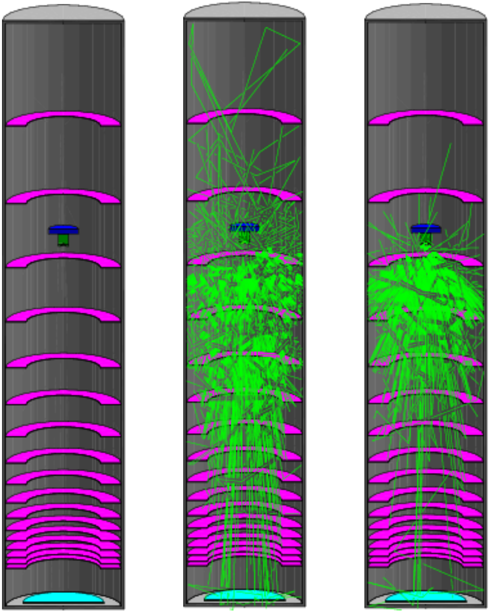
- Little knowledge exists about LAr attenuation
  - Few literature references and lacking information
  - Attenuation length depends strongly on the impurities in LAr (esp. water)
  - Typical values in literature range from 40 cm to $>$ 3 m
- Simulation in MaGe assuming different attenuation lengths
- total light extinction = attenuation + scattering

$\rightarrow$ $1/\lambda_{\text{net}} = 1/\lambda_{\text{att}} + 1/\lambda_{\text{scatt}}$

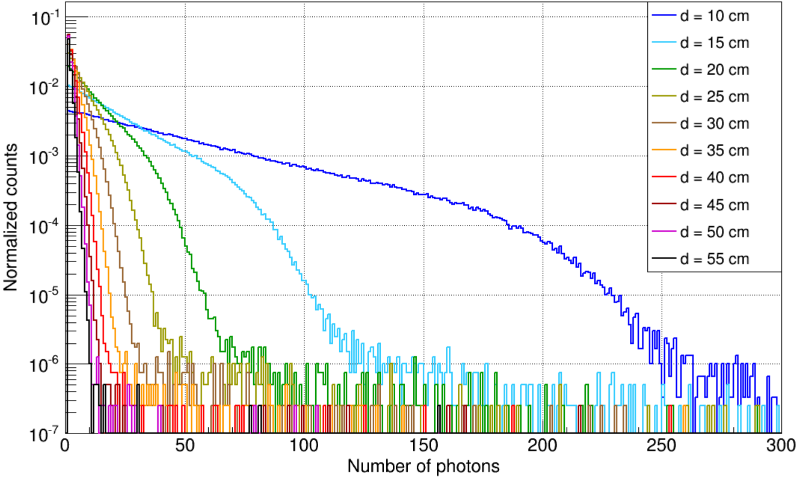
- Scattering in LAr is documented in literature:
  λ_{scatt} = 66 cm for 128 nm

  [N. Ishida, et al. Nucl. Instr. and Meth. A, vol. 384, pp. 380–386 (1997)]

Simulation of the Setup with d = 35 cm, λ_{att} = 60 cm



Simulation data for λ_{att} = 60 cm



Simulation data analysis

- Intensity of the scintillation light after distance d:

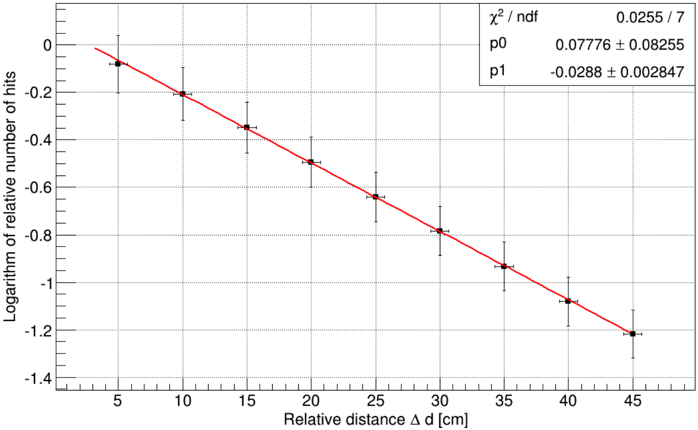
$$I_i = I_0 \cdot \mathrm{e}^{-d_i/\lambda}$$

- $\lambda =$ net light extinction length, distance where the intensity has dropped to 1/e $\approx$ 37%
- Choosing closest measuring point as reference:

$$\frac{I_i}{I_1} = \frac{\mathrm{e}^{-d_i/\lambda}}{\mathrm{e}^{-d_1/\lambda}}$$
$$\log \frac{I_i}{I_1} = -\frac{1}{\lambda} \underbrace{(d_i - d_1)}_{\Delta d}$$

- Plot the logarithm over Δd, assuming uncertainty of 0.5 cm
- Linear fit with slope of $-1/\lambda$

Simulation data analysis



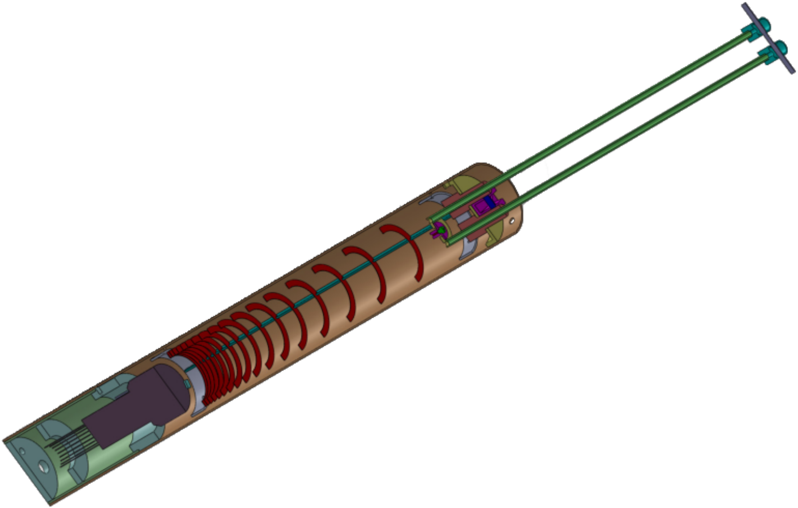
- $1/\lambda_{net} = 1/\lambda_{att} + 1/\lambda_{scatt} = 1/60 + 1/66 \Rightarrow \lambda_{net} = 31.4$ cm
- slope p1 $\rightarrow \lambda_{net} = 34.7 \pm 3.4$ cm

Conclusion & Outlook

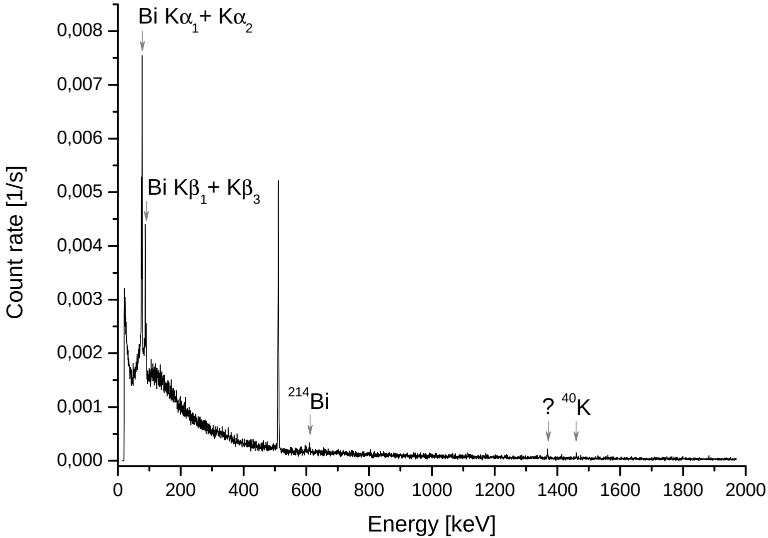
- Largest uncertainty: distance between PMT and source $\rightarrow$ net light extinction length can be measured to a few centimeters precisely (10-15% uncertainty in simulations)
- Preferring ^{90}Sr source with regard to statistics & effort
- Design of setup finalized $\rightarrow$ currently under construction
- PMT will be coated with WLS
- Plan to test the whole setup in LAr cryostat outside GERDA
- Some parts will be prepared with the help of other GERDA collaborating institutions
- Deploy in GERDA during Phase II preparations $\rightarrow$ expected in summer/autumn 2014

Backup

Setup design

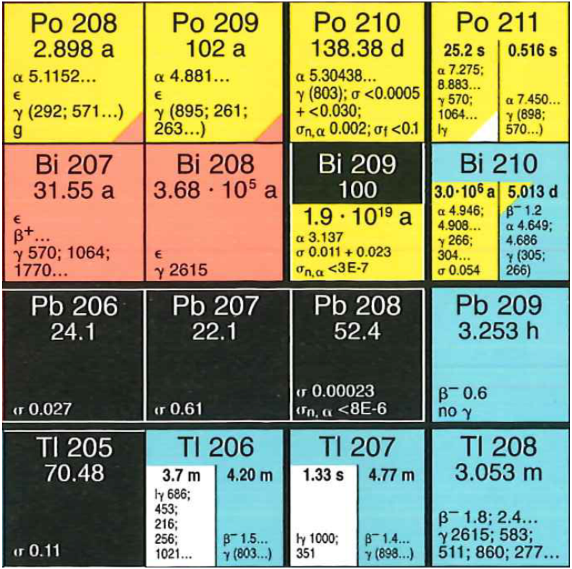


Results of the gamma spectrometry

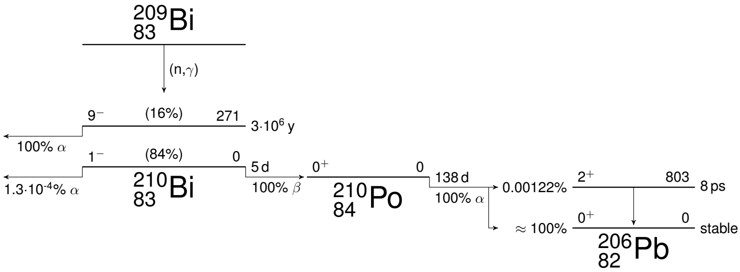


- Peak @ 511 keV from detector setup

^{210}Bi in the nuclide chart

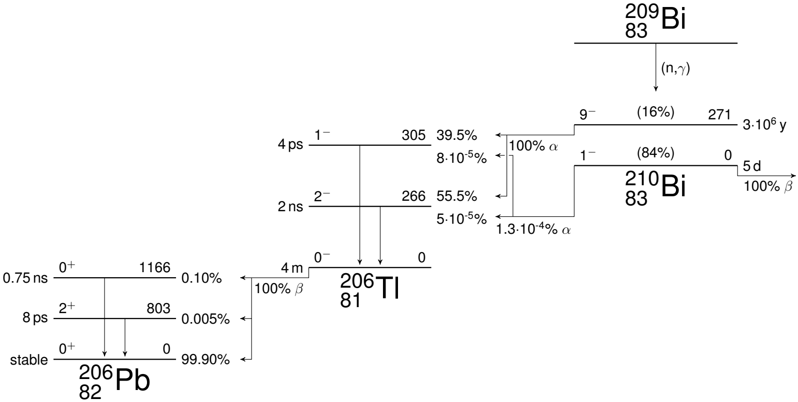


Activation of ^{209}Bi and decay chain of ^{210}Bi



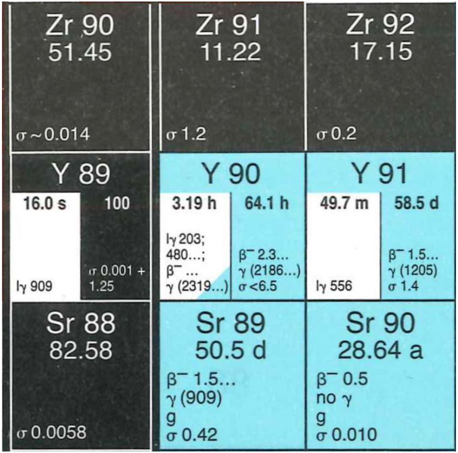
[Values from http://ie.lbl.gov/toi/, http://www.oecd-nea.org/janis/ $\rightarrow$ JEFF-3.1.2]

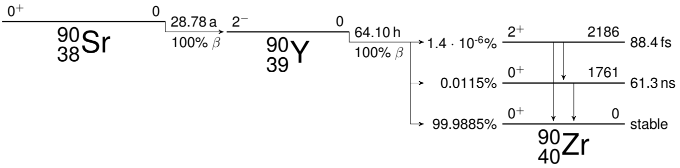
Activation of ^{209}Bi and decay chain of ^{210}Bi



[Values from http://ie.lbl.gov/toi/, http://www.oecd-nea.org/janis/ → JEFF-3.1.2]

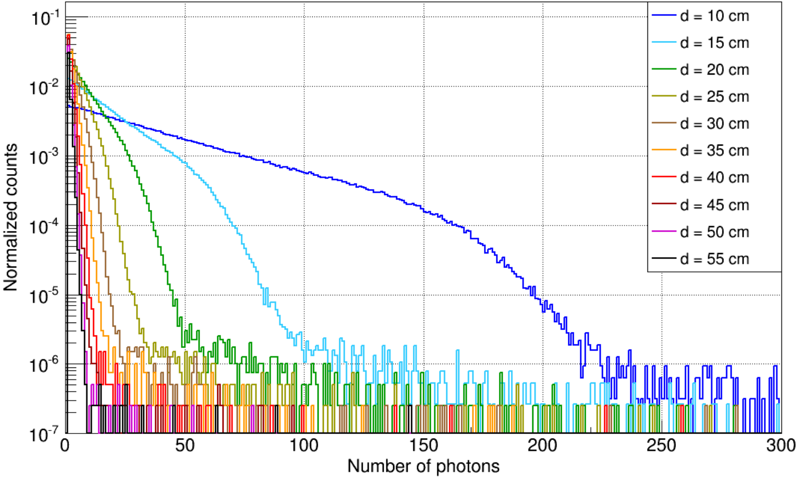
^{90}Sr in the nuclide chart



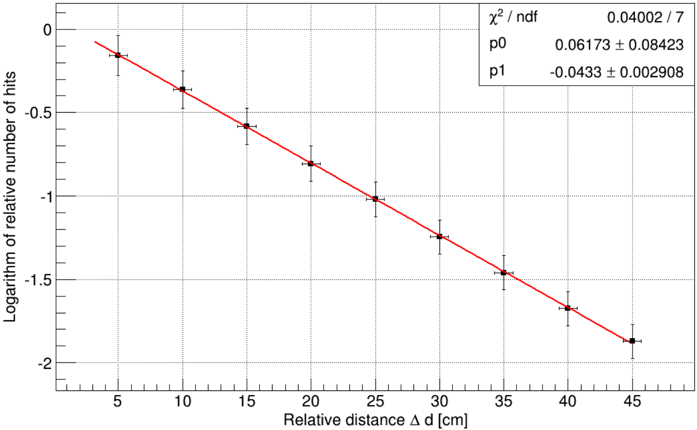


[Values from http://ie.lbl.gov/toi/]

Simulation data for λ_{att} = 30 cm

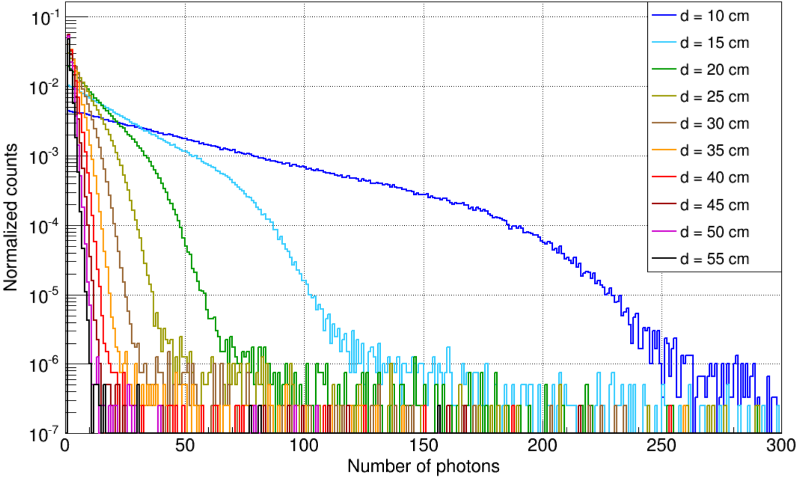


Simulation data analysis

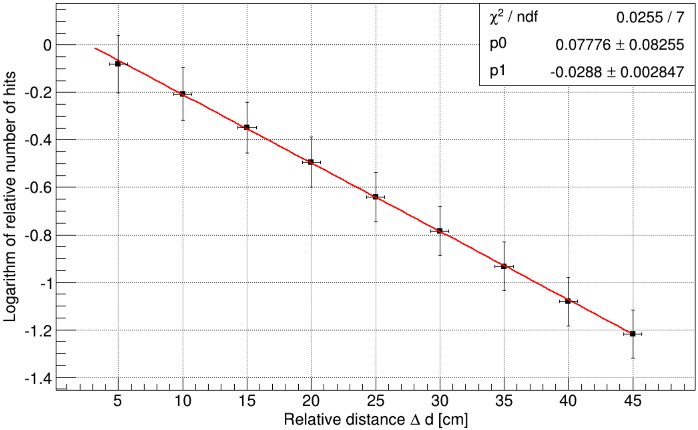


- $1/\lambda_{net} = 1/\lambda_{att} + 1/\lambda_{scatt} = 1/30 + 1/66 \Rightarrow \lambda_{net} = 20.6$ cm
- slope p1 $\rightarrow \lambda_{net} = 23.1 \pm 1.6$ cm

Simulation data for λ_{att} = 60 cm

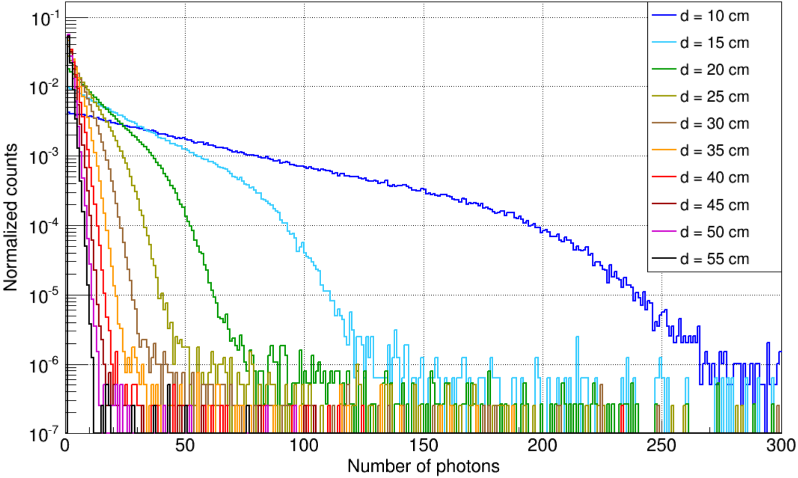


Simulation data analysis

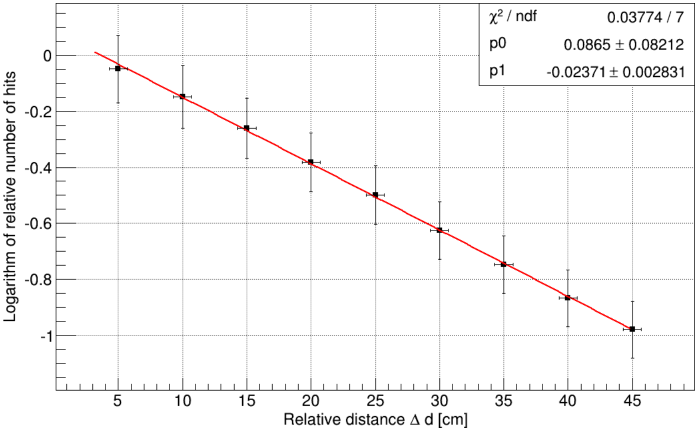


- $1/\lambda_{net}$ = $1/\lambda_{att}$ + $1/\lambda_{scatt}$ = 1/60 + 1/66 $\Rightarrow$ λ_{net} = 31.4 cm
- slope p1 $\rightarrow$ λ_{net} = 34.7 $\pm$ 3.4 cm

Simulation data for λ_{att} = 90 cm

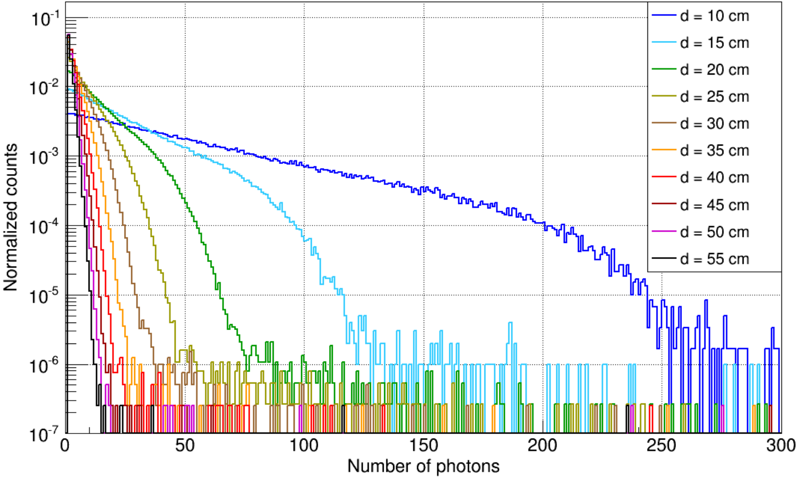


Simulation data analysis

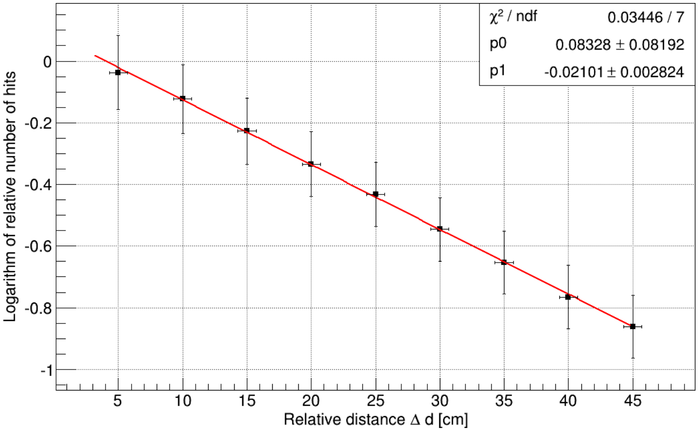


- $1/\lambda_{net} = 1/\lambda_{att} + 1/\lambda_{scatt} = 1/90 + 1/66 \Rightarrow \lambda_{net} = 38.1$ cm
- slope p1 $\rightarrow \lambda_{net} = 42.2 \pm 5.0$ cm

Simulation data for λ_{att} = 120 cm

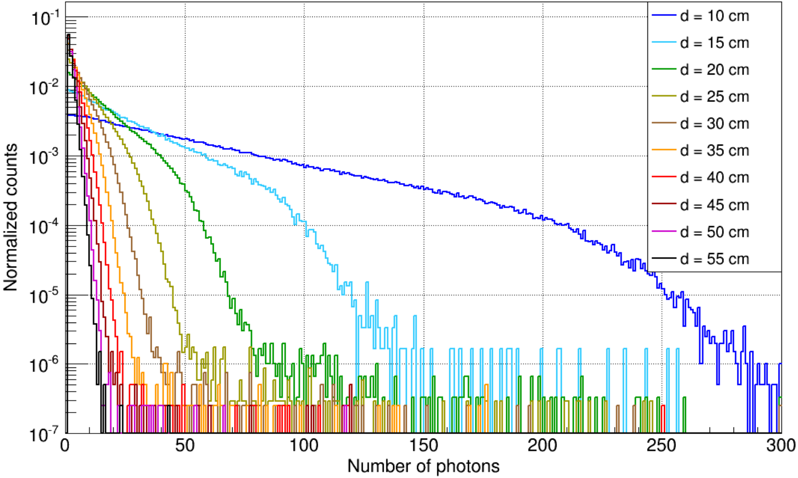


Simulation data analysis

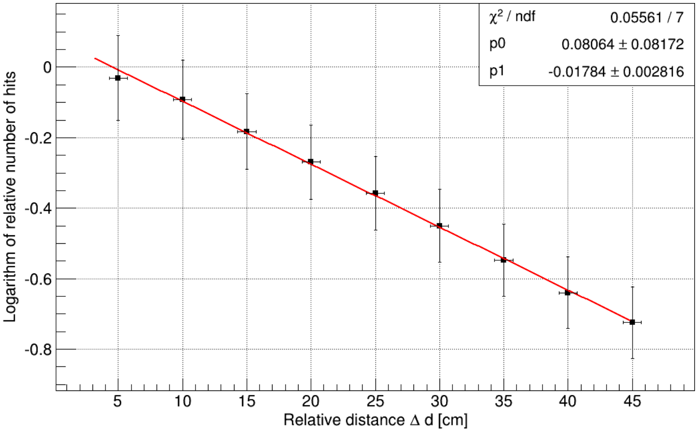


- $1/\lambda_{\text{net}} = 1/\lambda_{\text{att}} + 1/\lambda_{\text{scatt}} = 1/120 + 1/66 \Rightarrow \lambda_{\text{net}} = 42.6\,\text{cm}$
- slope p1 $\rightarrow \lambda_{\text{net}} = 47.7 \pm 6.4$ cm

Simulation data for $\lambda_{att} = 200$ cm

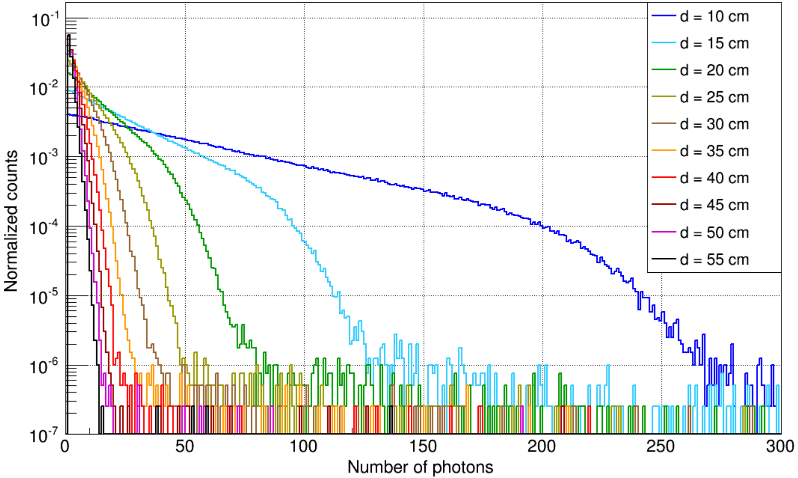


Simulation data analysis

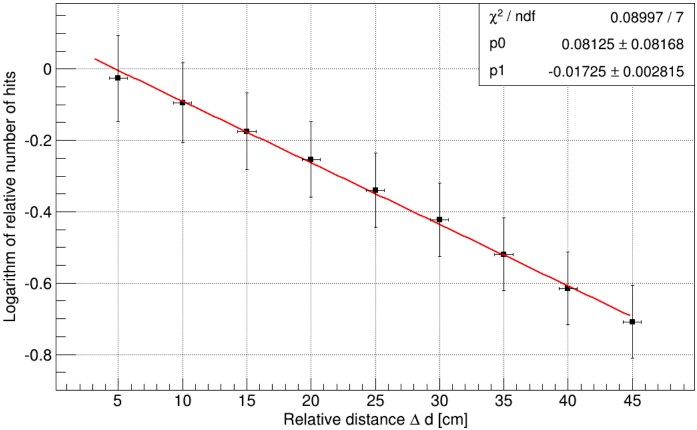


- $1/\lambda_{net} = 1/\lambda_{att} + 1/\lambda_{scatt} = 1/200 + 1/66 \Rightarrow \lambda_{net} = 49.6\,\text{cm}$
- slope p1 $\rightarrow \lambda_{net} = 56.1 \pm 8.9$ cm

Simulation without scattering for λ_{att} = 60 cm



Simulation without Rayleigh scattering



- $1/\lambda_{\text{net}} = 1/\lambda_{\text{att}} = 1/60 \Rightarrow \lambda_{\text{net}} = 60\,\text{cm}$
- slope p1 $\rightarrow \lambda_{\text{net}} = 58.0 \pm 9.5$ cm