A Generalized Model for Light Transport in Scintillators

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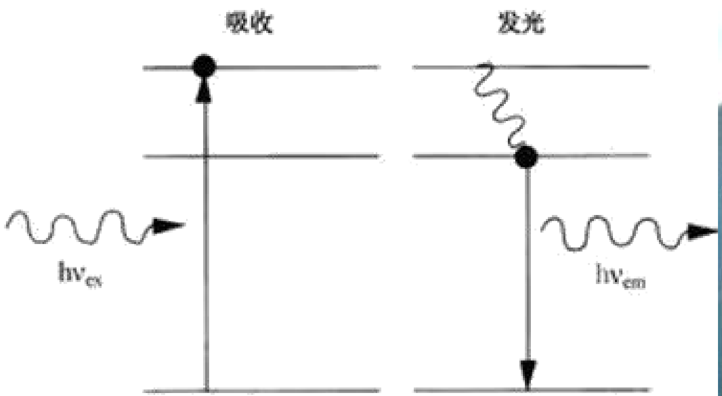
Introduction

Scintillators

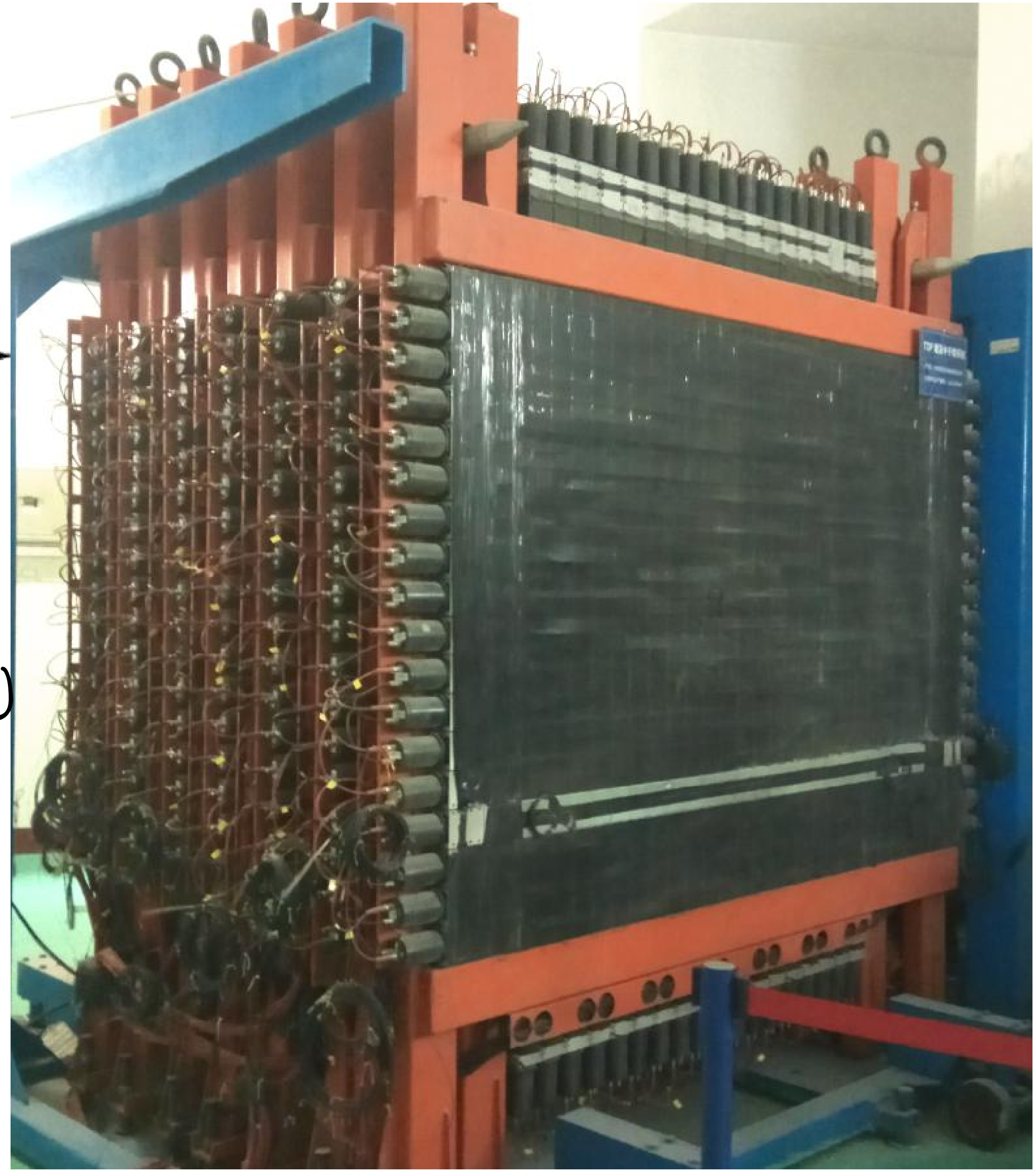
Introduction



Photomultiplier tube(PMT)

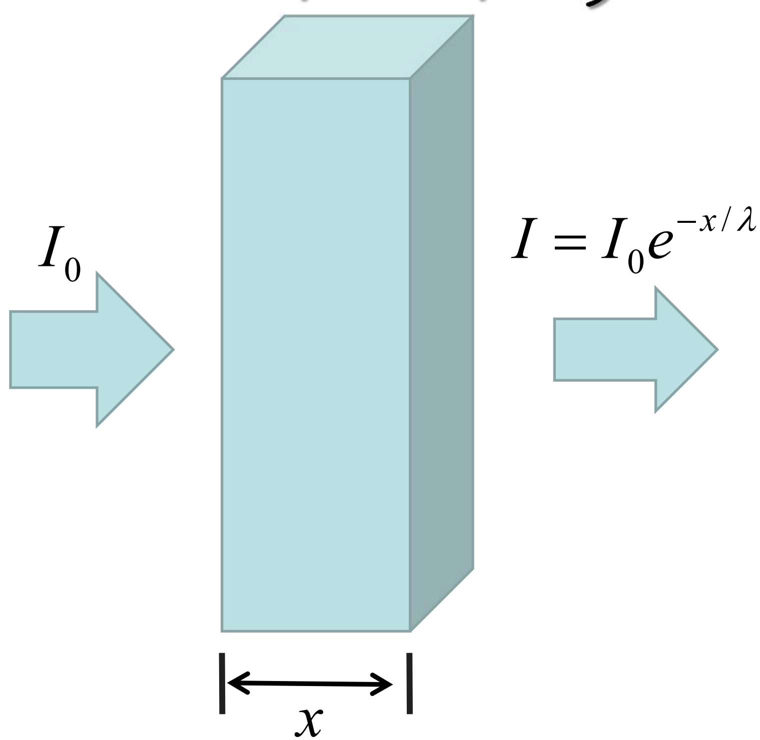
signal

extract： hit position or deposited energy



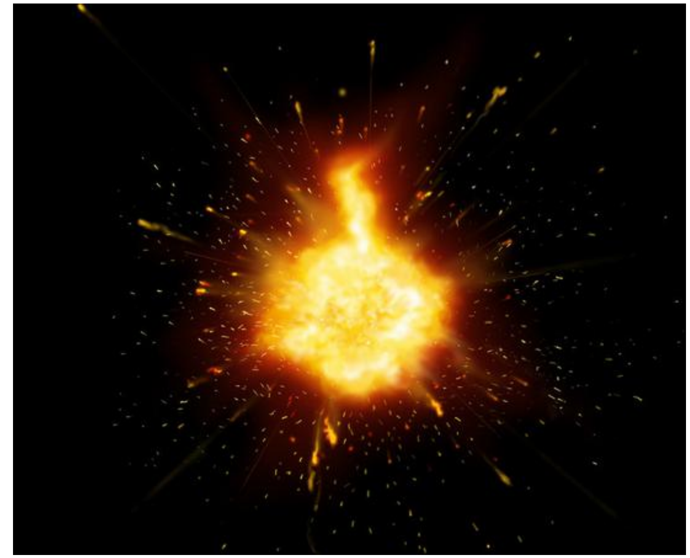
Light Transport

Intensity: decay length, λ



This formula only works in parallel light.
But the light is radial in Scintillators.

4π uniform



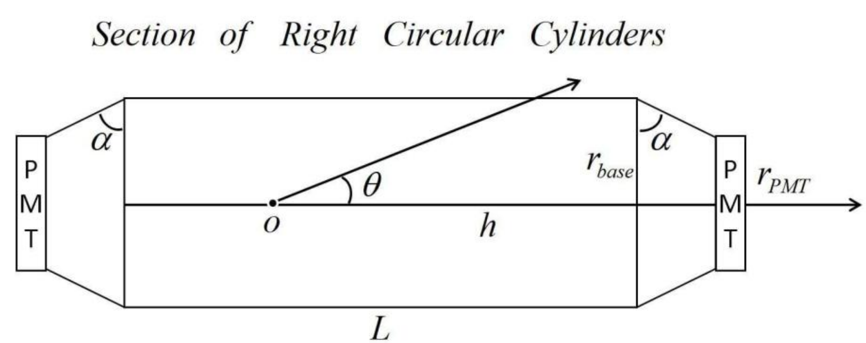
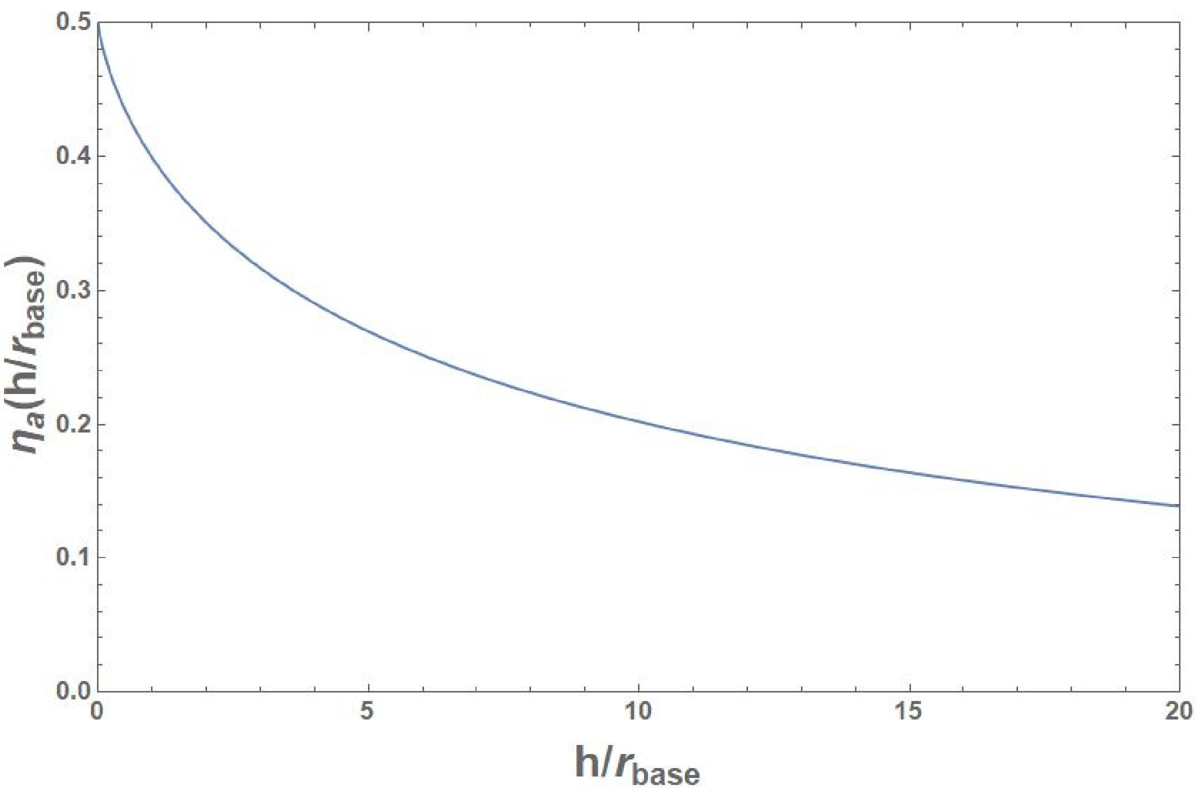


Figure 2: We analyse the geometric shape of scintillator as a right circular cylinders with base radius r_{base} and height L and the collection PMT is a right circular cylinders with base radius r_{PMT} contracted by a right conical frustum with top is scintillator's base and base is PMT's base and the base angle is α, and the position of emitted light on the axis with height h and θ direction for each light.

Light Transport

$$I_a(h/r_{base}) = I_0 \frac{2\pi}{4\pi} \int_0^{\pi/2} e^{-\frac{h/r_{base}}{\lambda cos\theta}} sin\theta d\theta$$

$$= I_0 \eta_a(h/r_{base}) e^{-\frac{h/r_{base}}{\lambda}},$$

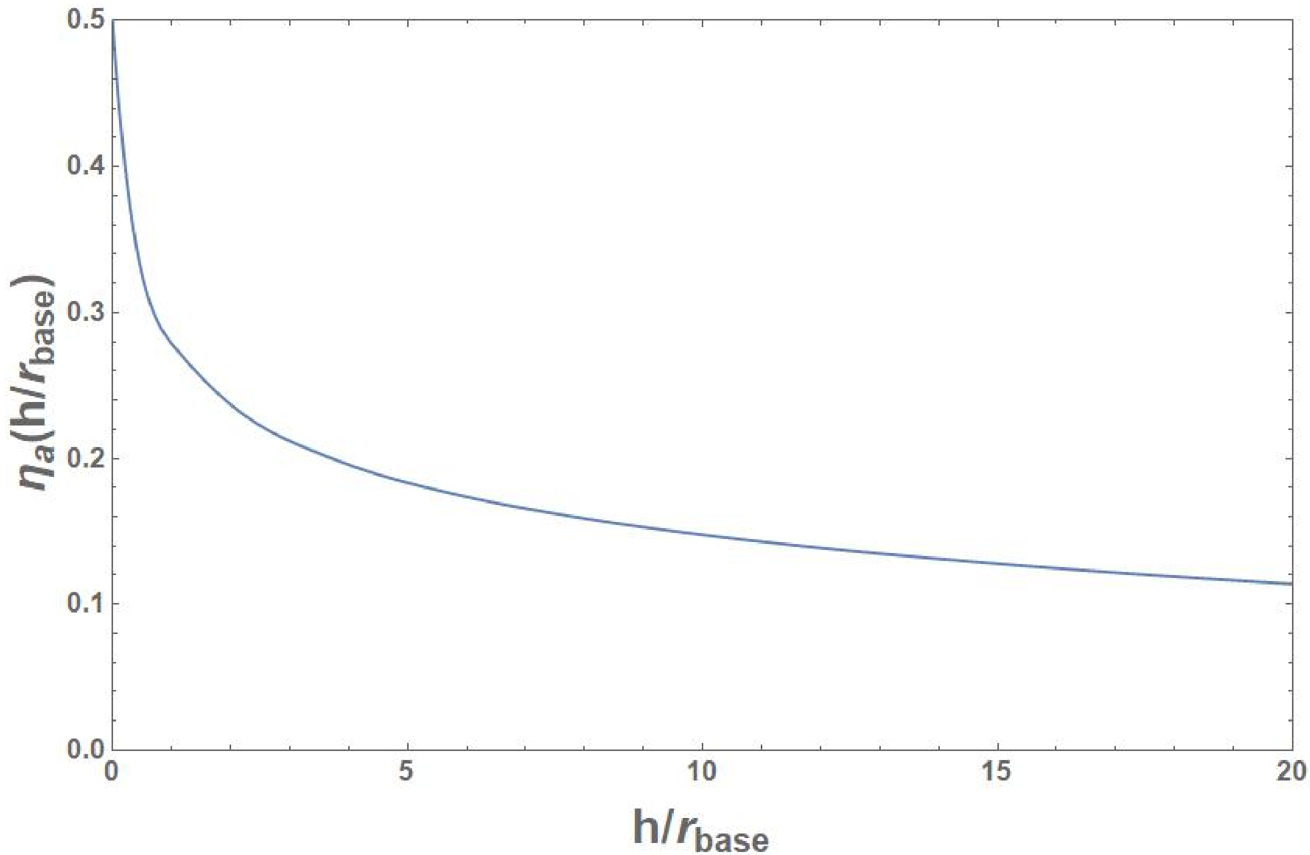


Correction fraction: describes the properties of the Scintillators

Light Transport

$$I_a(h/r_{base}) = I_0 \frac{2\pi}{4\pi} \int_0^{\pi/2} e^{-\frac{h/r_{base}}{\lambda cos\theta}} \left(\frac{sin(\pi/2-\theta)}{sin\theta_c}\right)^{\lfloor \frac{h/r_{base}+tan(\pi/2-\theta)}{2tan(\pi/2-\theta)} \rfloor} sin\theta d\theta$$

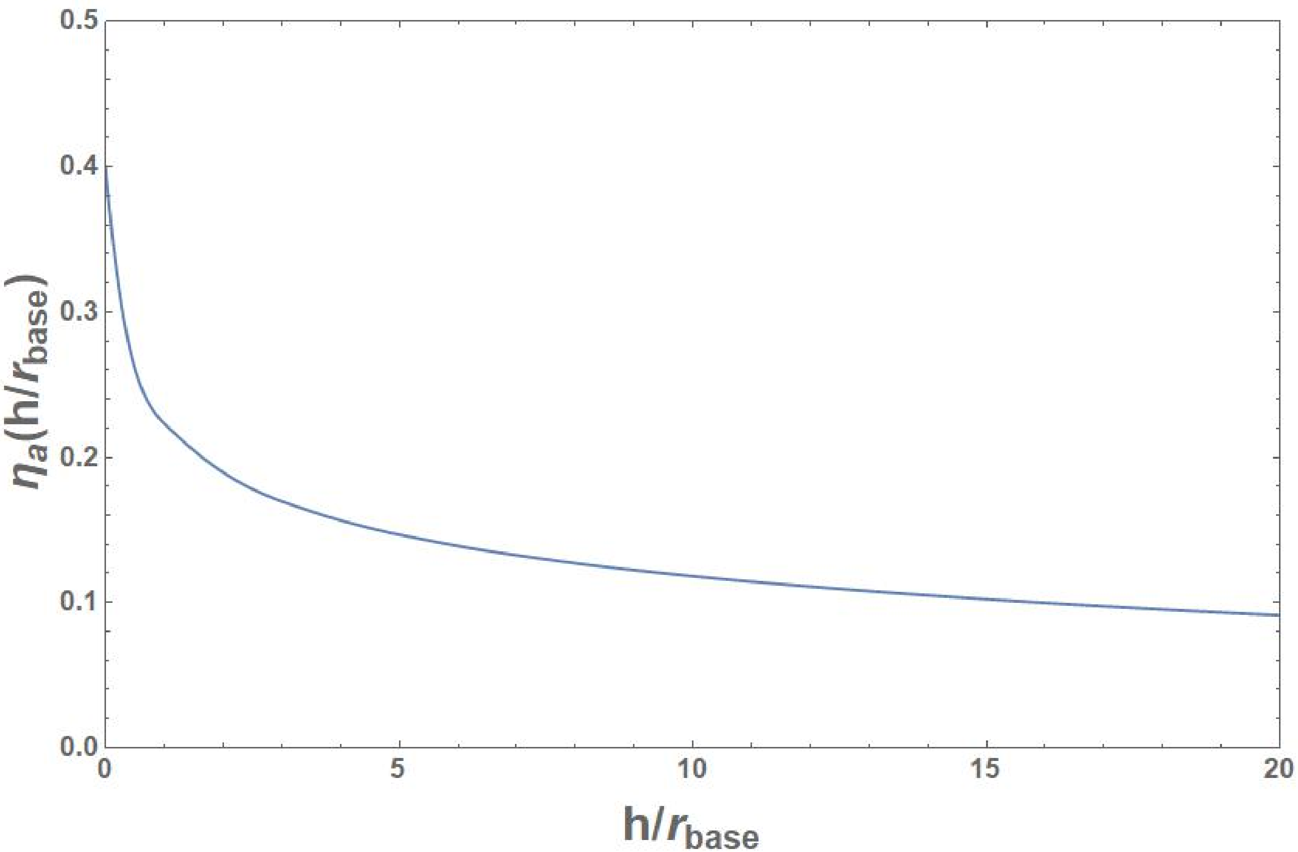
$$= I_0 \eta_a(h/r_{base}) e^{-\frac{h/r_{base}}{\lambda}},$$



Light Transport

$$I_a(h/r_{base}) = I_0 \frac{2\pi}{4\pi} \int_0^{\pi/2} e^{-\frac{h/r_{base}}{\lambda cos\theta}} \left(\frac{sin(\pi/2-\theta)}{sin\theta_c}\right)^{\lfloor \frac{h/r_{base}+tan(\pi/2-\theta)}{2tan(\pi/2-\theta)} \rfloor} R_a sin\theta d\theta$$

$$= I_0 \eta_a(h/r_{base}) e^{-\frac{h/r_{base}}{\lambda}},$$

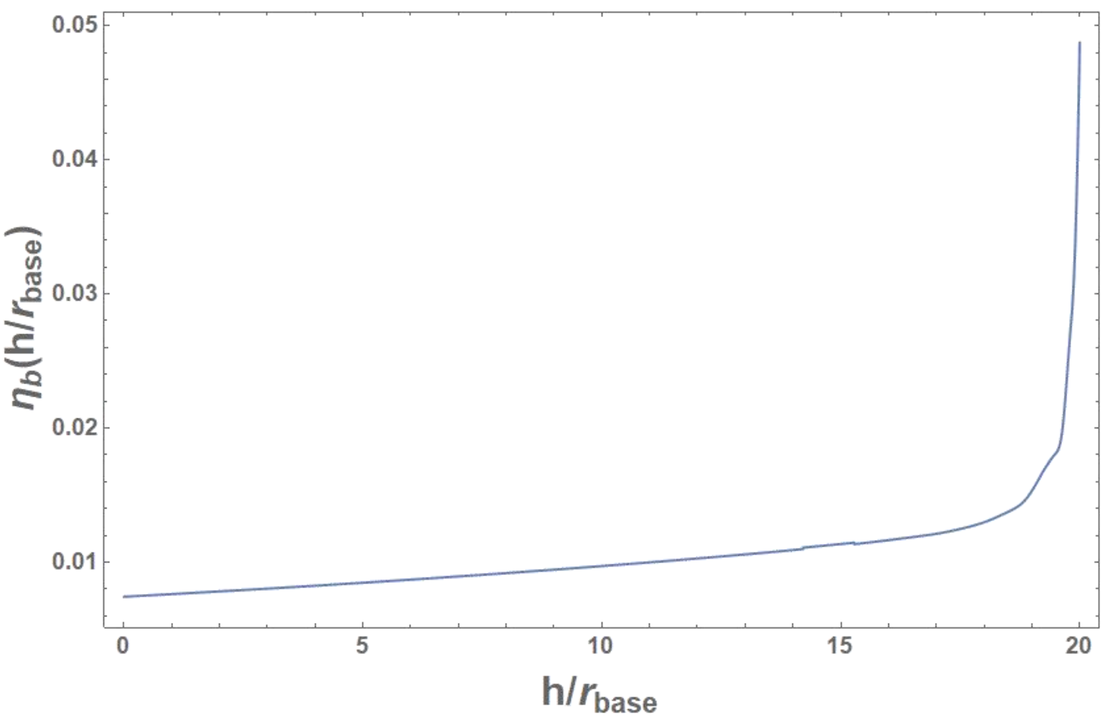


Light Transport

Integrate from **π**/2 to **π**.

$$I_b(h/r_{base}) = I_0 \frac{2\pi}{4\pi} \int_{\pi/2}^{\pi} ...sin\theta d\theta$$

$$= I_0 \eta_b(h/r_{base}) e^{-\frac{(2L-h)/r_{base}}{\lambda}},$$



Correction fraction: describes the properties of the Scintillators

Light Transport

$$I(x) = I_0\left(\eta_a(x)e^{-x/\lambda} + \eta_b(x)e^{-(2L-x)/\lambda}\right).$$

$$\eta_a(x) = e^{\frac{c_1}{c_2+x}} \qquad \eta_b(x) = \frac{c_3}{1-x/c_4}$$

Where the parameter :

c_1 and c_2 are in the same order of r_{base},

c_3 is in the order of r_{base}/L ,

c_4 is in the order of L.

$\eta_a(x) \rightarrow 1$ under $x \gg c_1$, and $\eta_b(x) \rightarrow 0$ under $x \ll L$.

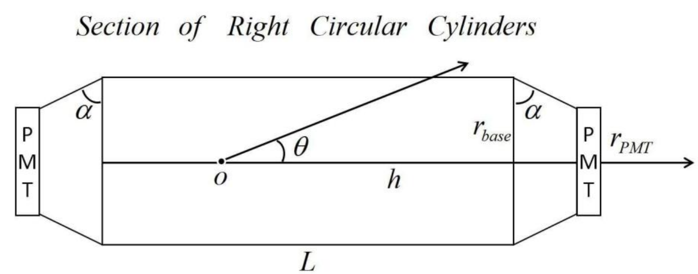


Figure 2: We analyse the geometric shape of scintillator as a right circular cylinders with base radius r_{base} and height L and the collection PMT is a right circular cylinders with base radius r_{PMT} contracted by a right conical frustum with top is scintillator's base and base is PMT's base and the base angle is α, and the position of emitted light on the axis with height h and θ direction for each light.

Result

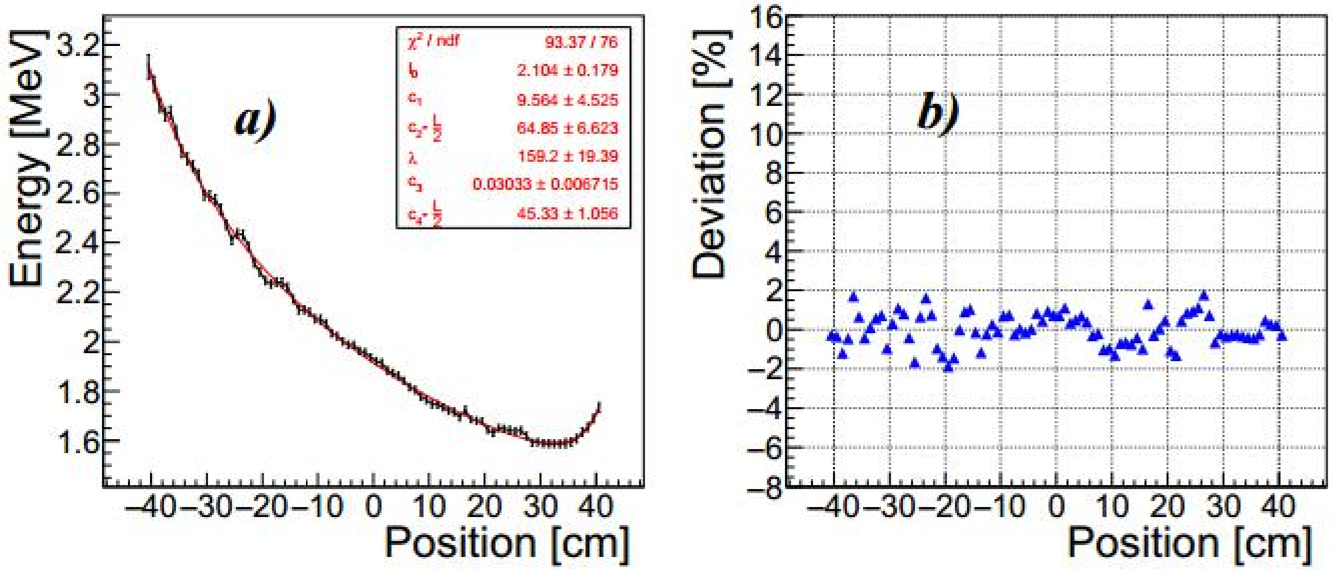
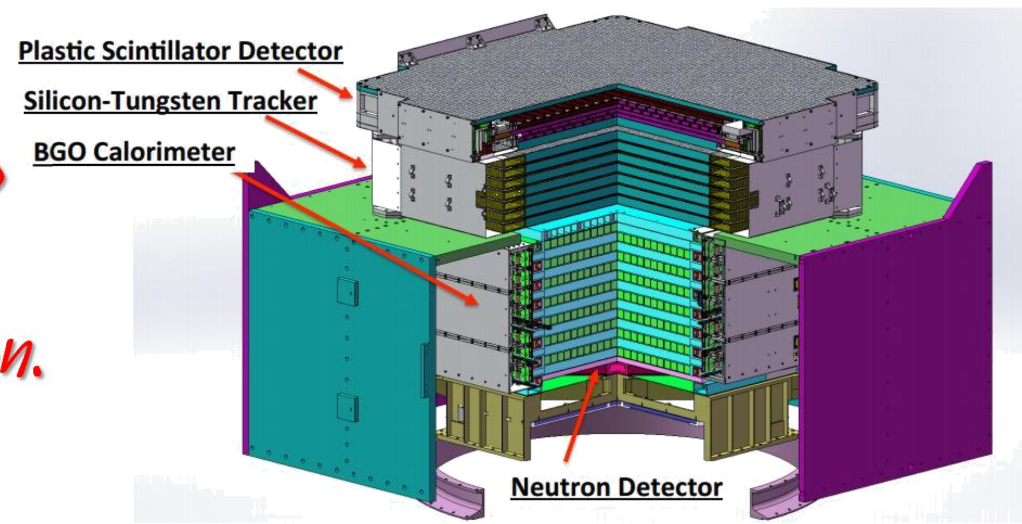


Figure 4: (Color online) a) The curve fitted with the samples from PSD at DAMPE by our model under converting length coordinates to position coordinates. b) The deviation between our new model fitting function and the samples.

Our model is used to do calibration/allignment by DAMPE Collaboration.

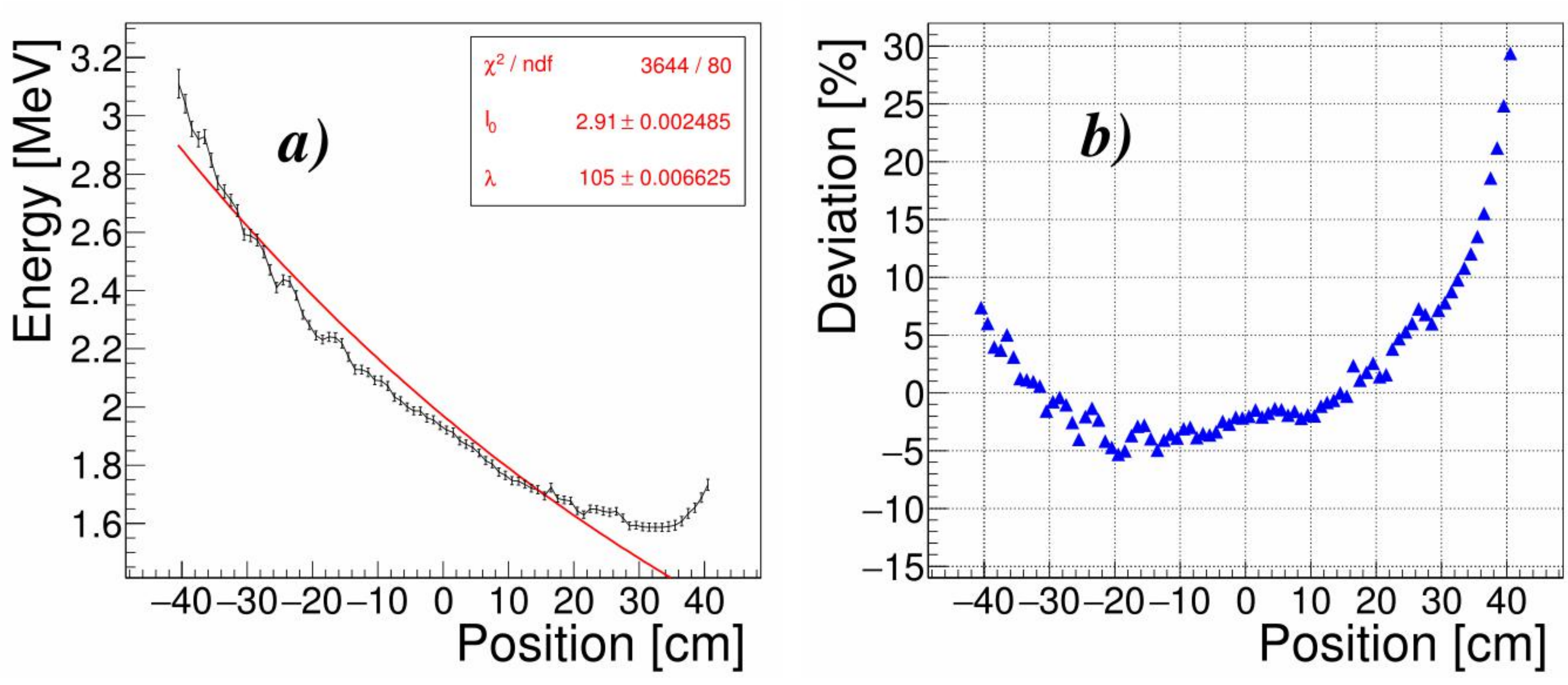


Result: Case-I

$$I(x) = I_0 e^{-x/\lambda}.$$

exponential decay

Not good !!

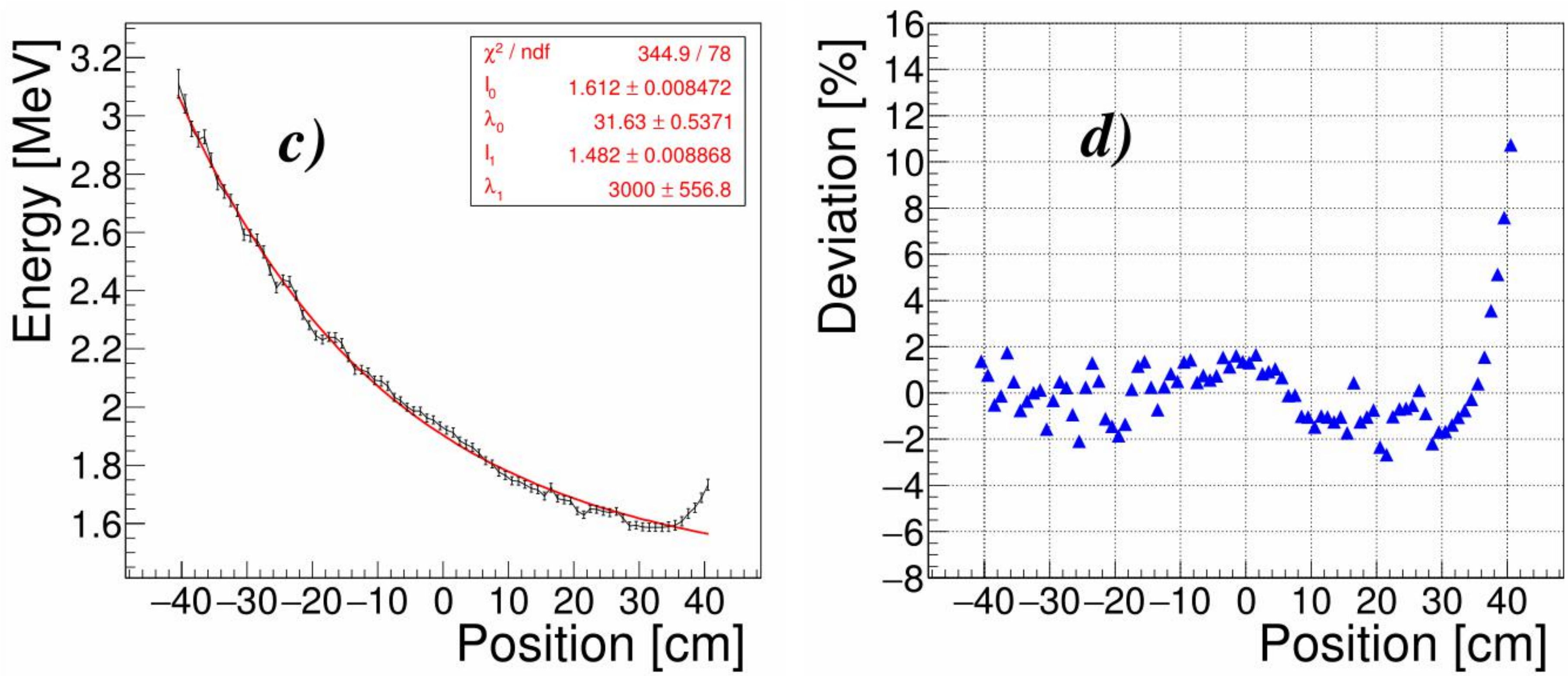


Result: Case-II

Still not so good !!

$$I(x) = I_1 e^{-x/\lambda_1} + I_2 e^{-x/\lambda_2},$$

Ref: IEEE Transactions on Nuclear Science. Publication Year: 1964, Page(s):29- 37

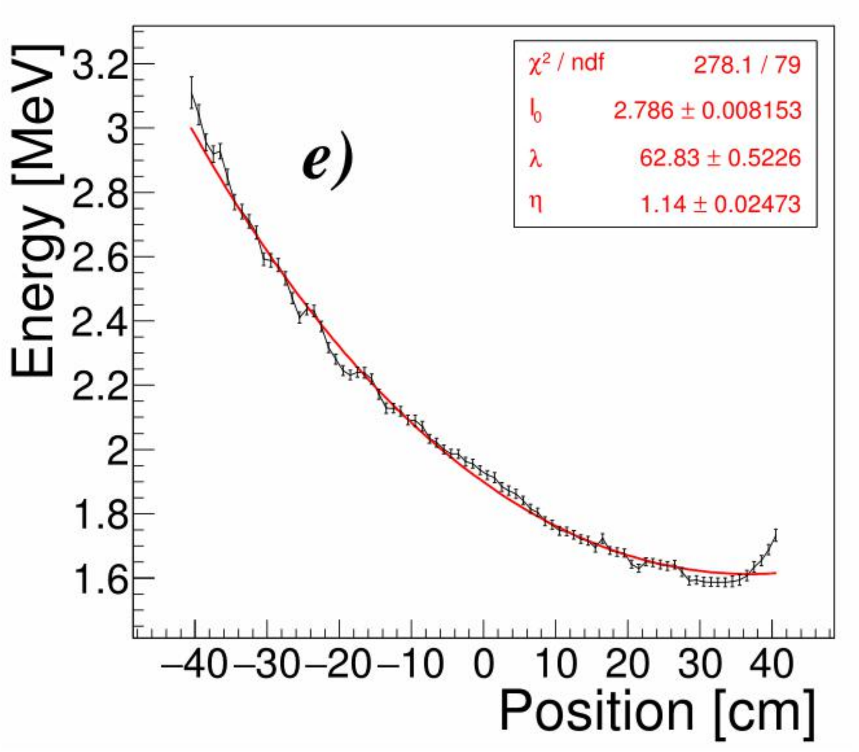


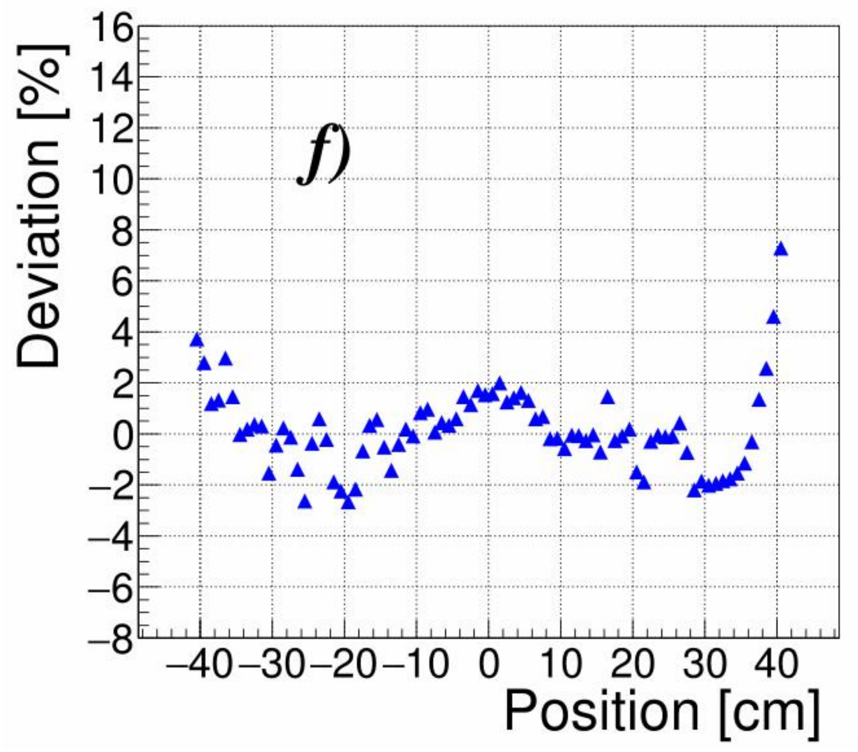
Result : Case -III

Not so bad !!

$$I(x) = I_0(e^{-x/\lambda} + \eta e^{-(2L-x)/\lambda}).$$

Ref: Nuclear Instruments and Methods in Physics A 370(1996)429-434





Result: Comparison

$$\delta(x) = \frac{I_{experimental\ data}(x) - I_{fitting}(x)}{I_{fitting}(x)}.$$

Table 1: Compare The Deviation With Other Models

	ED model	DE model	RB model	our model
δ_{max}	29%	11%	7%	<2%
χ^2/ndf	3644/80	344.9/78	278.1/79	93.4/76

Case -I Case -II Case -III

Result: our model

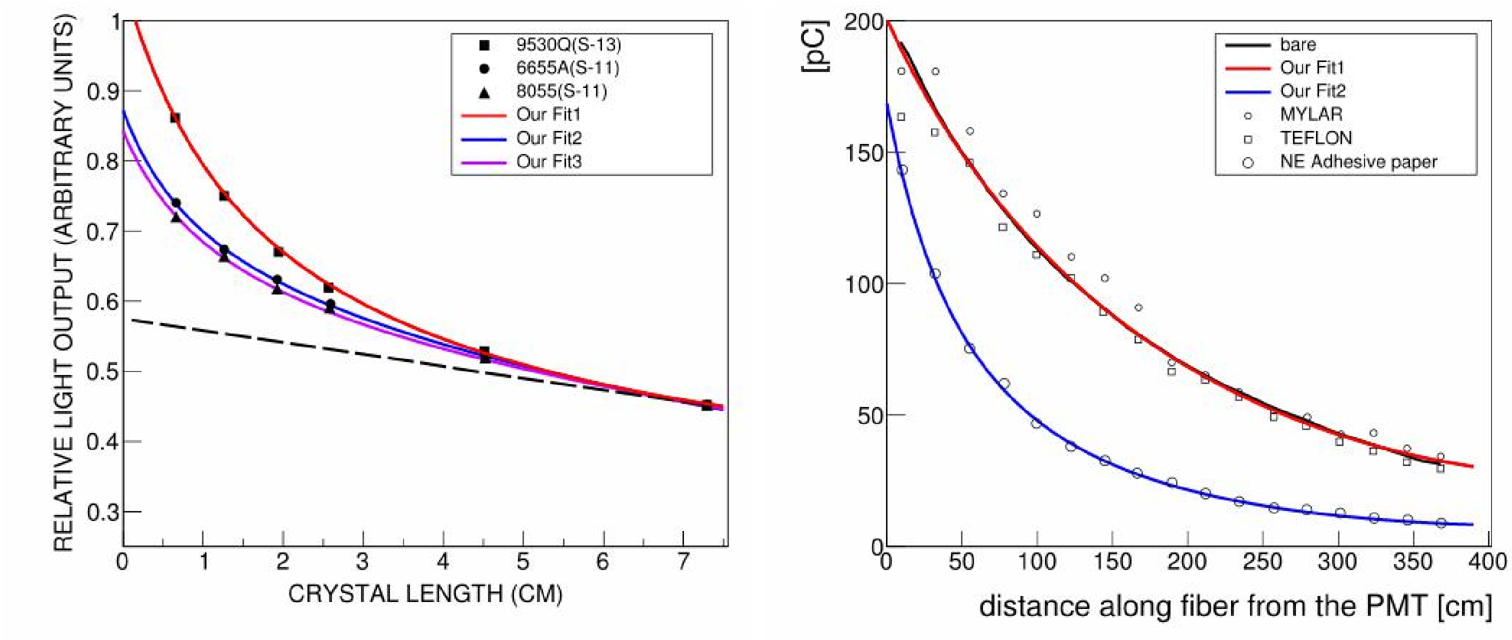


Figure 5: (Color online) left) All the data are from Kaiser's experiment data about light output with length[8], and the three thick lines are our model fitting result. right) All the data are from Taiuti's experiment data about light output with length[9], and the two thick lines are our model fit result.

[8] IEEE Transactions on Nuclear Science. Publication Year: 1964, Page(s):29- 37

[9] Nuclear Instruments and Methods in Physics A 370(1996)429-434

Result: our model

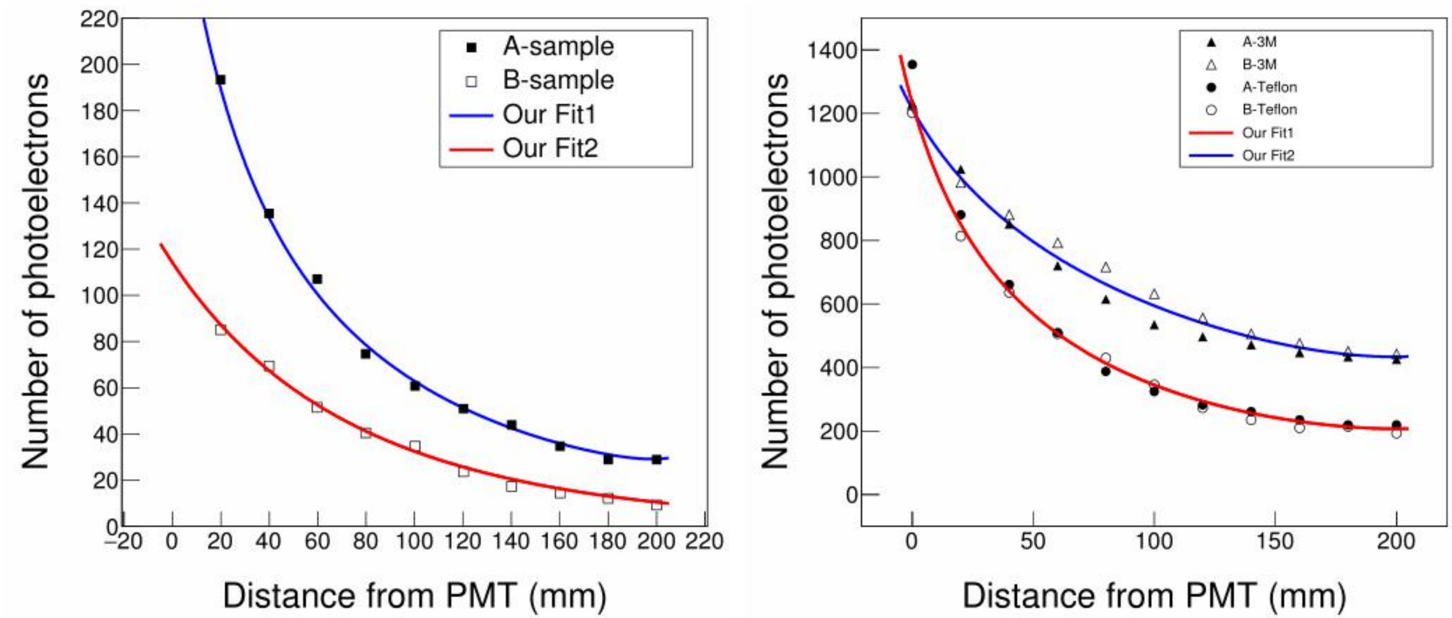


Figure 6: (Color online) All the data are from Gierlik's experiment data about light output with length[10], and the all thick lines are our model fitting result.

[10] Nuclear Instruments and Methods in Physics Research A 593 (2008) 426–430

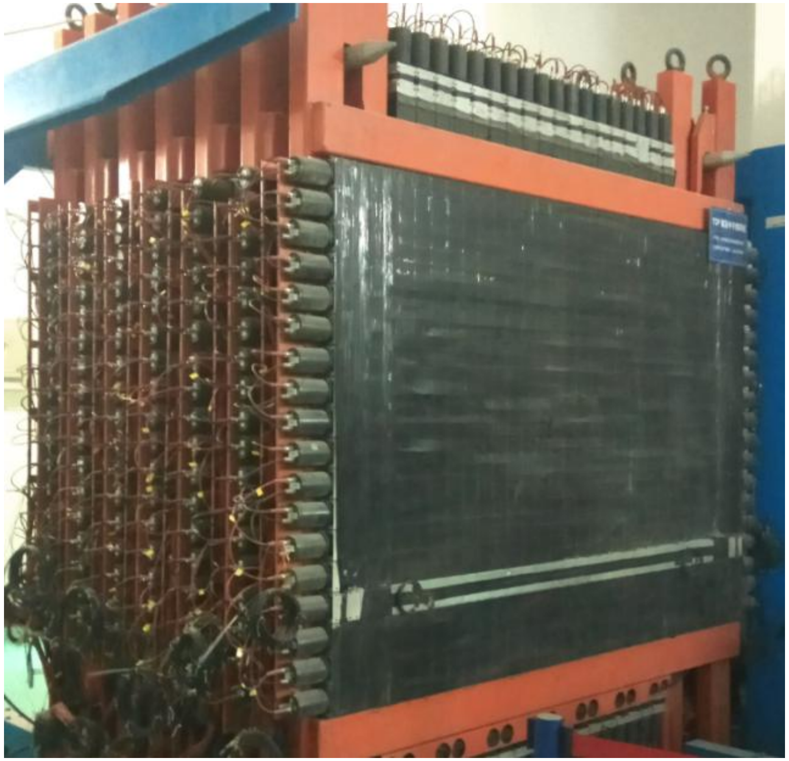
Light Transport: How to get the energy of the particle ?

$$I(x) = I_0\Big(\eta_a(x)e^{-x/\lambda} + \eta_b(x)e^{-(2L-x)/\lambda}\Big).$$

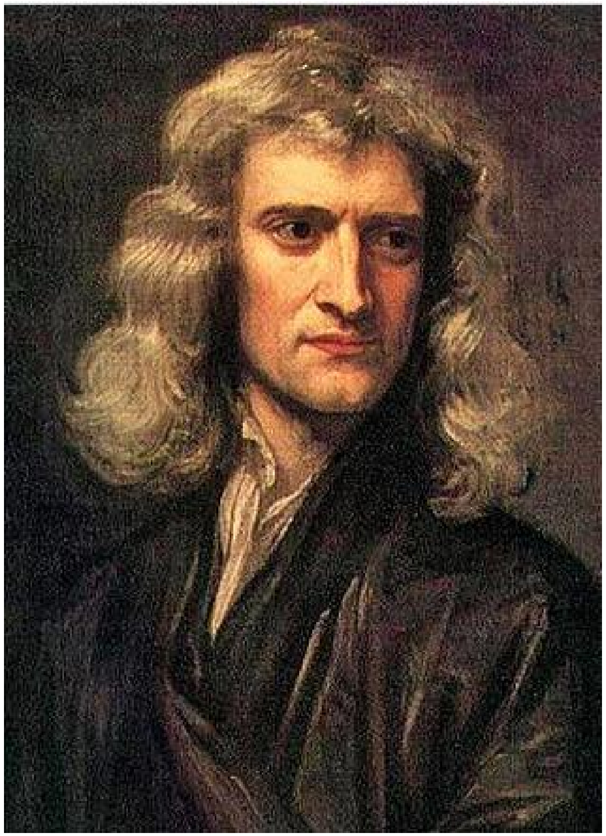
Extract the particle Energy:

$$E_{cor} = \frac{E_{adc}}{I(x)}$$

It can work in half number of PMT, and saves cost.

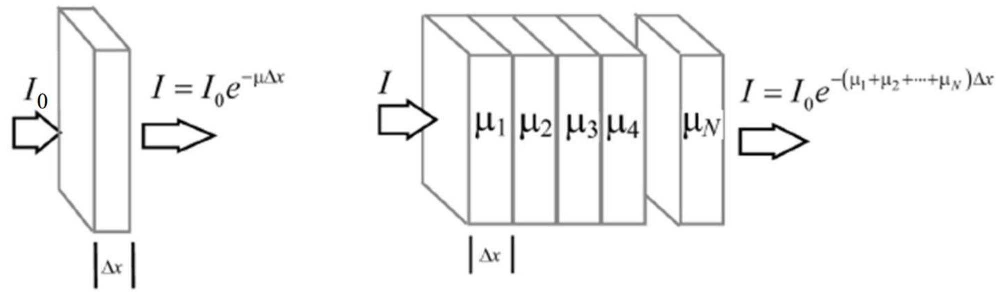


By the way--->>>



Isaac Newton

LHC Collaboration considers small cell one by one for light transport in scintillators, as follows:



$$I = I_0 e^{-\mu\Delta x}$$

$$I = I_0 e^{-\mu_1\Delta x} e^{-\mu_2\Delta x} e^{-\mu_3\Delta x} \cdots e^{-\mu_n\Delta x} = I_0 e^{-\sum_{n=1} \mu_n \Delta x}$$

This model likes calculus and needs a lot calculation. But it is very powerful.

Anyway, our model is simple without a lot calculation.

Thank you for your attention,
please question.