Investigation of heavy inorganic scintillators for a fiber-based Compton camera

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Abstract

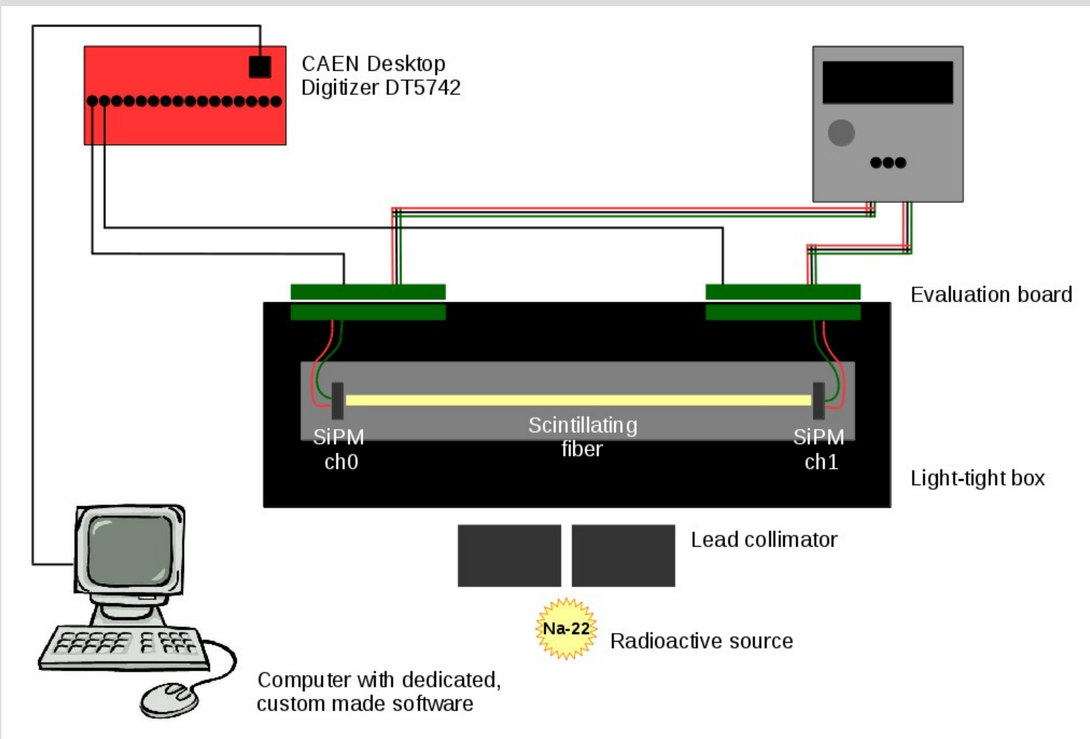
Since proton therapy has become an important cancer treatment modality, the research towards quality assurance and online treatment monitoring has intensified. Detection of prompt gamma radiation emitted during the patient's irradiation is among the most promising methods for online monitoring of deposited dose distribution, with Compton camera type detectors being a natural choice for this purpose. Recent development in production of inorganic scintillators resulted in a variety of materials, many of which are characterized by large densities, excellent timing properties and light yield, as well as mechanical properties allowing to manufacture thin fibers. When combined with modern silicon photomultipliers (SiPMs), they allow compact and granular detector designs suitable for detection of several-MeV prompt gamma radiation.

In order to investigate properties of heavy inorganic scintillating materials a dedicated test-bench has been constructed. The study was focused on lutetium based crystals (LuAG:Ce, LYSO:Ce). All samples had an elongated, fiber-like shape with 1 x 1 mm^2 cross section and 100 mm length. The following properties of the materials have been investigated: attenuation length of the scintillating light, timing characteristics, energy resolution and light output. In those aspects LYSO:Ce was found to perform better than LuAG:Ce.

Experimental setup

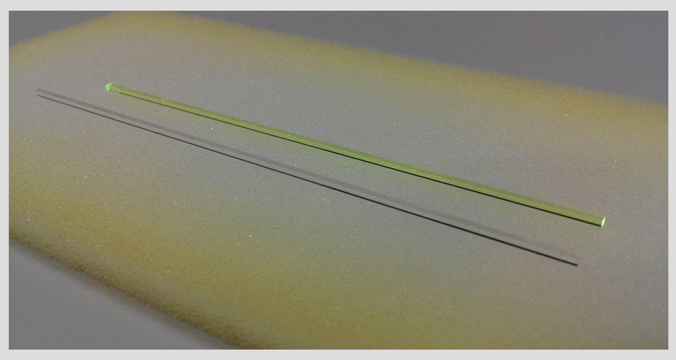
The experimental setup consist of the light-tight box in which the investigated scintillating fiber is placed. The fiber is coupled to the SiPMs on both ends. The radioactive souce with lead collimator placed on the movable and remotely controlled platform allow for irradiation of the investigated scintillator at the desired position.

Data acquisition is handled by the CAEN Desktop Digitizer, which samples incoming siglans and saves full waveforms. Data analysis is performed using custom written software.



Scheme of the experimental setup.

Heavy inorganic scintillators



Investigated scintillating fibers: LuAG:Ce (yellow) and LYSO:Ce (transparent).

	LuAG:Ce	LYSO:Ce
Formula	$Lu_3Al_5O_{12}$:Ce	Lu_2YSiO_5:Ce
Density [g/cm^3]	6.73	7.1
Z_{eff}	63	65
Reffraction index (at max emission)	1.84	1.81
Maximum of emission [nm]	535	420
Decay constant [ns]	70 (44%) 1063 (56%)	40-45
Photon yield [ph/MeV]	2.5 x 10^4	3 x 10^4
Photoelectron yield [% of NaI:Tl]	20	75
Radiation length at 511 keV [cm]	1.3	1.2
Attenuation length [cm]	5 – 30	~40
Energy resolution at 662 keV [%]	8 – 8.5	7

Determined decay constants:

- LuAG:Ce fast component (138 ± 3) ns → 30%
- LuAG:Ce slow component (1300 ± 170) ns → 70%
- LYSO:Ce (57 ± 3) ns

Data from producers websites: www.crytur.cz www.epic-crystal.com

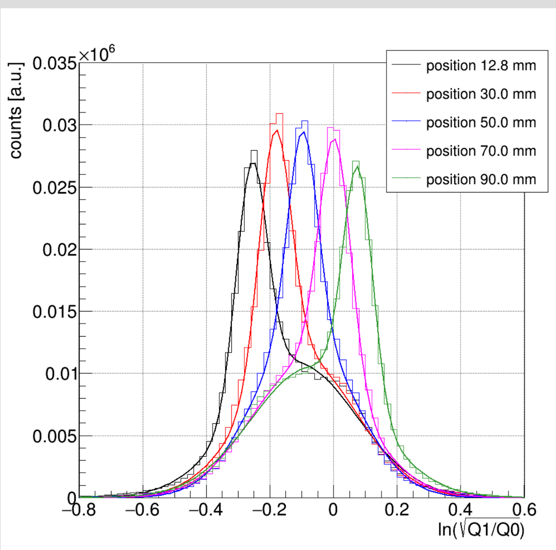
Attenuation length

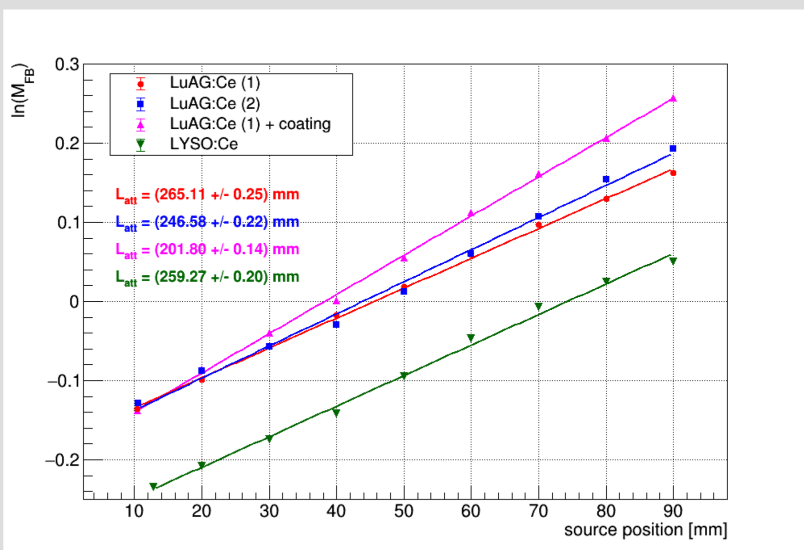
Attenuation length indicates the penetration depth of the light emitted in the scintillation process inside the scintillator itself. Having gamma spectra registered at different positions *z* along the investigated scintillating fiber the attenuation length can be determined as follows:

$$\ln(M_{FB}(z)) = A_0 + \frac{z}{L_{att}}$$

where $M_{FB}(z)$ describes relative light output at both ends of the fiber and it's given as:

$$M_{FB}(z) = \sqrt{\frac{ch0(z)}{ch1(z)}}$$



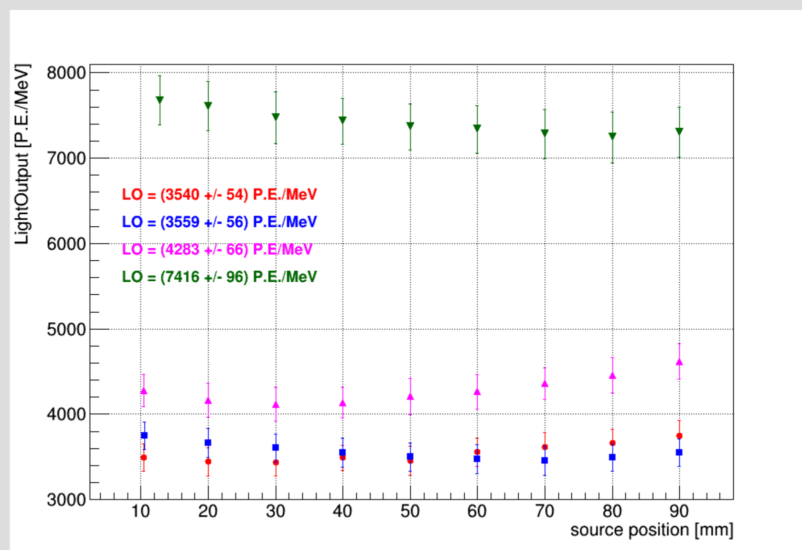


Light output

Light output has been determined as follows:

$$LO = \frac{n_{PE}}{E \cdot C_{PDE} \cdot e^{z/L_{att}}}$$

where E is energy, n_{PE} in number of photoelectrons and C_{PDE} is photo-detection efficiency. Losses due to fiber-SiPM copuling or any other factos has beed neglected in this case.

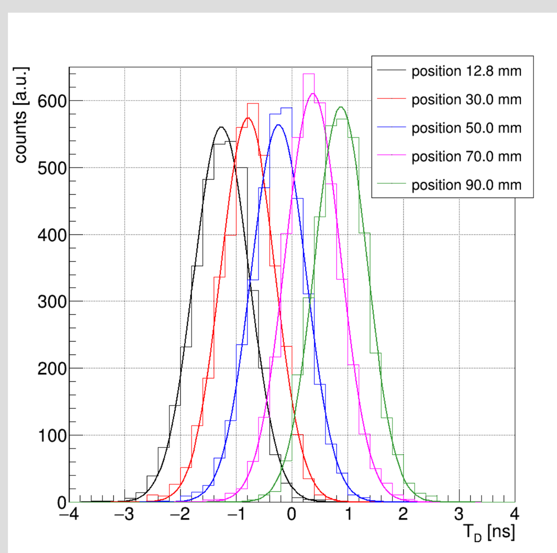


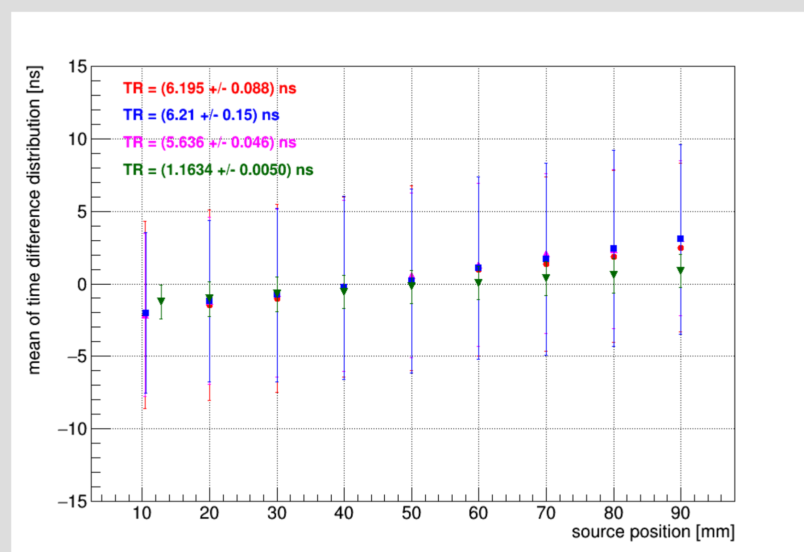
Timing resolution

Timing resolution of the investigated fibers results from time difference between correlated events being registered at both ends of the fiber:

$$T_D = T_{0\,ch0} - T_{0\,ch1}\,.$$

The T_D distribution is described by gaussian function and timing resolution is its *FWHM*. Only events in the 511 keV peak have been taken into account in the timing resolution determination in order to further improve this characteristics.

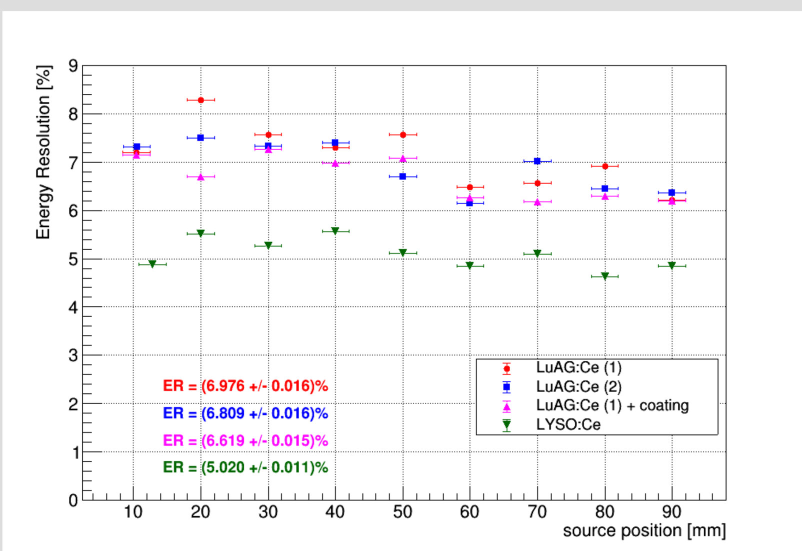




Energy resolution

Energy resolution has been determined for both ends of the fiber separately as a ratio of the width (σ) of the background-subtracted 511-keV peak to its position (μ):

$$ER = \frac{\sigma_{511}}{\mu_{511}} \cdot 100\,\%$$



Summary and further research

- Comparison between the two scintillating fibers from the same production batch showed no significant differences in light output and timing resolution, while they differ slightly in attenuation length.
- Comparison between naked fiber and fiber coated with the Al foil showed, that coating reduces attenuation length, but at the same time improves light output.
- From the two investigated materials LYSO:Ce shows better timing properties and light output, which makes it more suitable for future application in PGI detectors.

Future plans include:

- Investigation influence of other coatings *e.g.* white paint, teflon.
- Replacementlead collimator with an 'electronic collimator', which will result in significant background supression.

References

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