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# Report of LuAG:Ce Ceramic Fibers for the RADiCAL Detector Concept

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***Abstract*–HEP experiments at future hadron colliders require fast and radiation hard calorimetry. An ultra-compact RADiCAL electromagnetic calorimetry with radiation hard LYSO:Ce as active material and LuAG:Ce scintillating fibers as wavelength shifter is under development. We report an investigation on Φ1 mm LuAG:Ce ceramic fibers produced by using laser heated pedestal growth method at Shanghai Institute of Ceramics. Their photoluminescence spectra, quantum yield, and longitudinal uniformity were measured and compared to Y-11 fiber and quartz capillary wavelength shifters.**

## I. Introduction

An LYSO/W/quartz capillary shashlik calorimeter has been under development in the last decade for the high luminosity large hadron collider (HL-LHC), where an absorbed dose up to 100 Mrad, a charged hadron fluence up to $6\times10^{14}$ p/cm$^2$, and a fast neutron fluence up to $3\times10^{15}$ n/cm$^2$ are expected. Cerium doped lutetium-aluminum garnet ceramic scintillators ($Lu_3Al_5O_{12}$:Ce, or LuAG:Ce) was measured to have a factor of two better radiation hardness than LYSO:Ce crystals against γ-rays, protons, and neutrons.

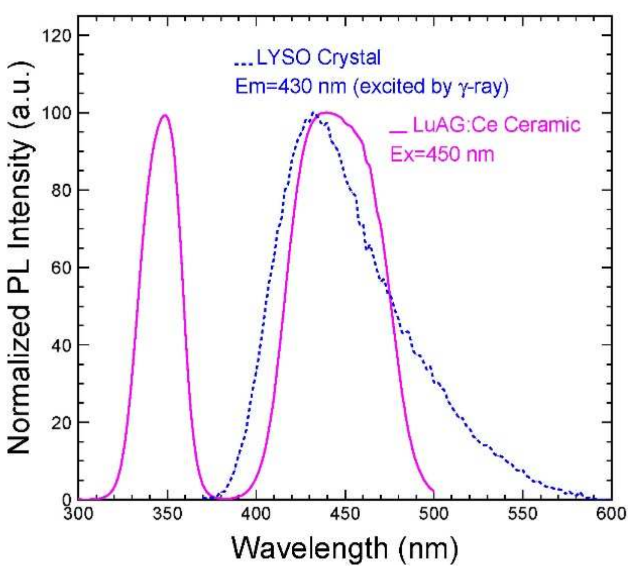


Fig. 1 LYSO emission spectra excited by γ-rays (blue dots) matches well LuAG:Ce ceramic excitation spectra (magenta lines).

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Fig. 1 shows LYSO:Ce emission spectrum (blue dots) peaked at 430 nm matches LuAG:Ce excitation spectrum peaked at 450 nm (magenta lines), indicating that LuAG:Ce may serve as a wavelength shifter (WLS) for LYSO:Ce. LuAG:Ce WLS fibers are considered for an ultra-compact, radiation hard and fast-timing shashlik calorimetry, or RADiCAL. In addition, a short LuAG:Ce segment at the electromagnetic shower maximum may provide precision timing for electrons and photons.

We measured photoluminescence (PL) spectra, quantum yield, and longitudinal uniformity for several Φ1 mm LuAG:Ce ceramic fibers and compared them to a Y-11 WLS fiber and a quartz capillary.

## II. Experimental Details

Fig. 2 shows 11 LuAG:Ce ceramic fibers of Φ1×40 mm$^3$, 3 LuAG:Ce ceramic fibers of Φ1×60 mm$^3$, and 2 LuAG:Ce ceramic fibers of Φ1×120 mm$^3$ fabricated at Shanghai Institute of Ceramics (SIC) by using laser heated pedestal growth method.

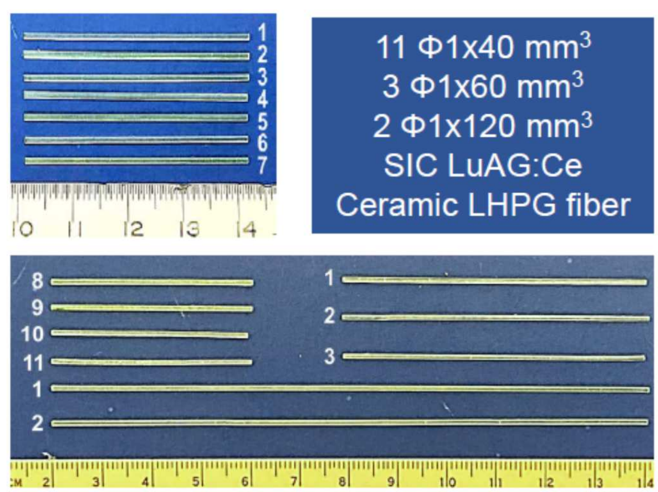


Fig. 2 11 LuAG:Ce fibers of Φ1×40 mm$^3$, 3 LuAG:Ce fibers of Φ1×60 mm$^3$, and 2 LuAG:Ce fibers of Φ1×120 mm$^3$ fabricated at SIC.

Their excitation and emission spectra were measured by using an Edinburgh spectrophotometer FLS920. An Edinburgh integrating sphere was integrated into the spectrometer and was used to measure their quantum yield with a Φ1×40 mm$^3$ quartz road as reference. Fig. 3 shows a home-made test bench used to measure longitudinal uniformity for various WLS. The samples were excited by a 420 nm LED at several positions. Light output was measured with two alternative ends coupled to a F4500 spectrophotometer through a Φ1 mm quartz fiber.

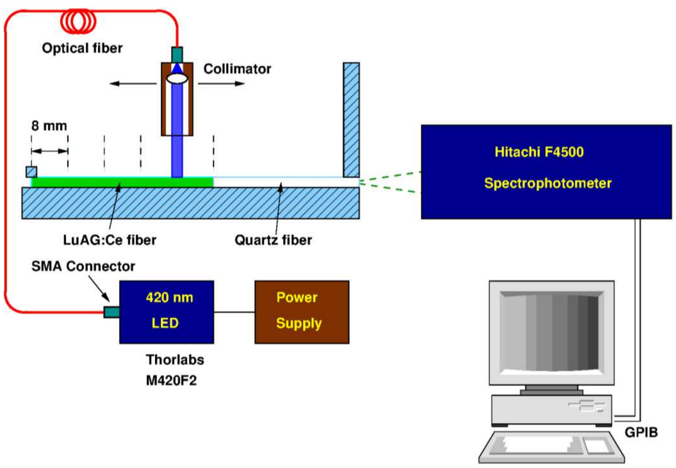


Fig. 3 A test bench used to measure longitudinal uniformity for WLS.

## III. Results and Discussion

Fig. 4 compares PL excitation (dashed lines) and emission (solid lines) spectra measured for a LuAG:Ce ceramic fiber (black) and a Y-11 (red)fiber of Φ1×40 mm$^3$ and a quartz capillary (blue) of Φ1×160 mm$^3$. The LuAG:Ce fiber shows a typical $Ce^{3+}$ excitation band peaked at 445 nm, and a broad emission band from 490 to 600 nm. The PL intensity of the LuAG:Ce fiber is less than the Y-11 fiber but comparable to the quartz capillary. The LuAG:Ce PL emission intensity with 420 nm excitation (black dots) is about one third of that with 445 nm excitation (solid black line), which is consistent with the excitation spectrum shown in the plot.

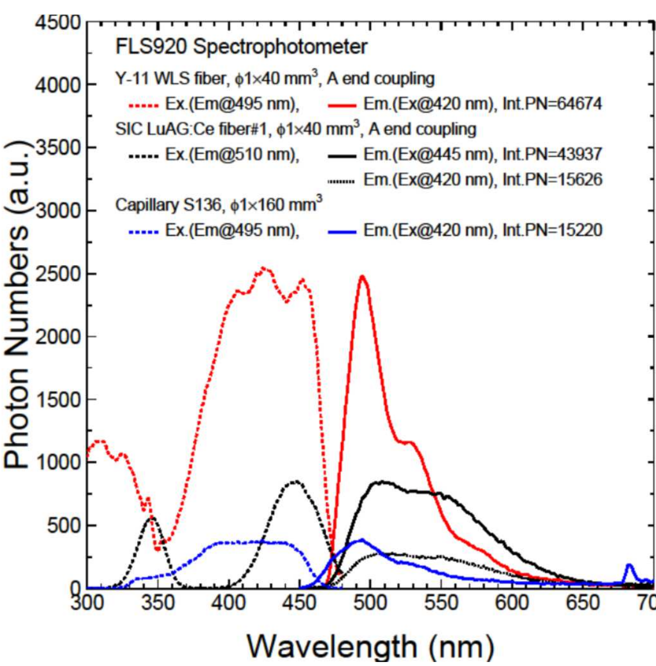


Fig. 4 PL excitation (dashes) and emission (solid) spectra are shown for a LuAG:Ce fiber (black) and a Y-11 fiber (red) of Φ1×40 mm$^3$ and a quartz capillary (blue) of Φ1×160 mm$^3$.

The quantum yield (η) of WLS was measured as 0.88±0.05 for a LuAG:Ce fiber of Φ1×60 mm$^3$, which can be compared to 0.87±0.05 for a Y-11 WLS fiber.

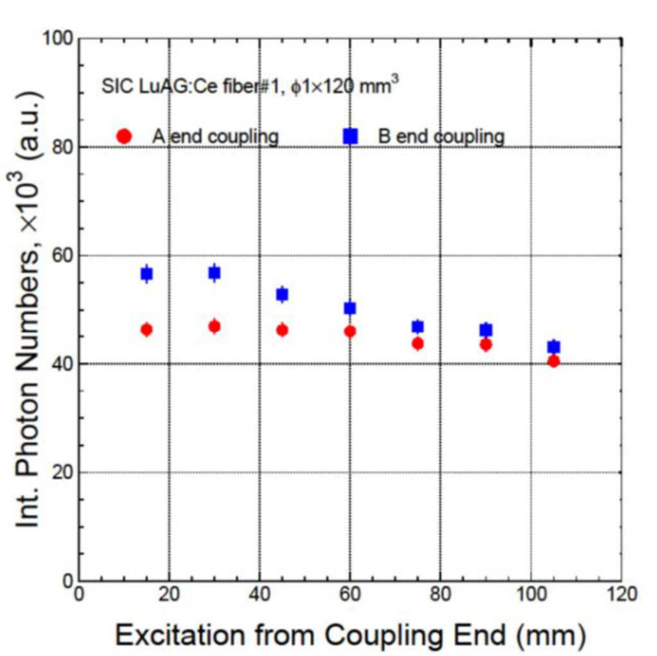


Fig. 5 Integrated PL emission photon numbers are shown as a function of the excitation position for a LuAG:Ce fiber of Φ1×120 mm$^3$ with A (red) and B (blue) end coupling.

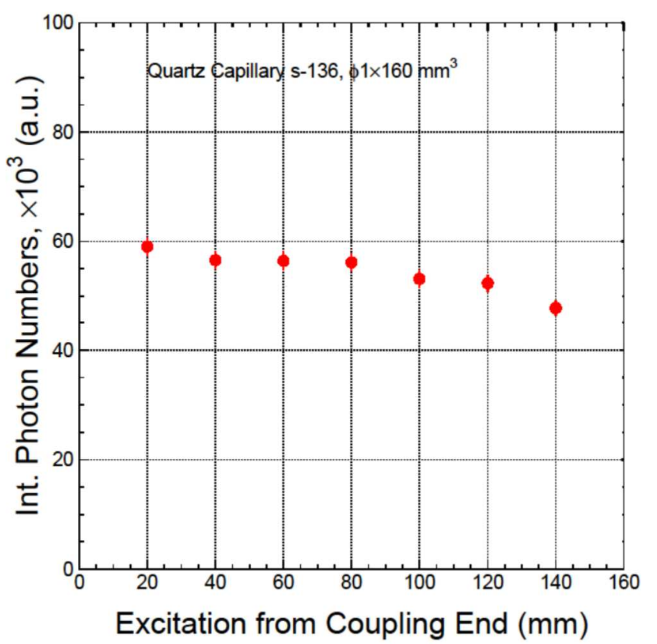


Fig. 6 Integrated PL emission photon numbers are shown as a function of the excitation position for a quartz capillary of Φ1×160 mm$^3$.

Figs. 5 and 6 show the integrated PL emission photon numbers as a function of the excitation position for a LuAG:Ce fiber of Φ1×120 mm$^3$ and a quartz capillary of Φ1×160 mm$^3$. Good intensity and uniformity were observed for the 120 mm long LuAG:Ce fiber for the A end coupling.

The corresponding rms value is 5.0%, which can be compared to 6.5% for the longer quartz capillary.

## IV. Summary

Future HEP experiments at the HL-LHC and the proposed FCC-*hh* require fast and radiation hard calorimetry. The RADiCAL concept utilizes bright, fast and radiation hard LYSO:Ce crystals as the sensitive material and LuAG:Ce as WLS for an ultra-compact, radiation hard and fast-timing shashlik calorimeter. A total of 16 Φ1 mm LuAG:Ce ceramic fibers of 4, 6 and 12 cm were fabricated by using Laser Heated Pedestal Growth technique at SIC. This 1st batch of LuAG:Ce WLS fibers show a quantum yield of up to 88% with light output and uniformity comparable to quartz capillary. R&D will continue to improve optical and scintillation quality of LuAG:Ce ceramic fibers.

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