INITIAL RESULTS OF TRANSVERSE BEAM PROFILE MEASUREMENTS USING A LYSO:Ce CRYSTAL*

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Abstract

A prototype transverse beam profile monitor for eventual use at the Advanced Superconducting Test Accelerator (ASTA) has been tested at the Fermilab A0 Photoinjector. Results from low-charge (20 pC) studies indicate that a LYSO:Ce scintillator will be a viable alternative to a YAG:Ce scintillator when using intercepting radiation convertor screens for beam profiling. We will also describe the planned implementation of LYSO:Ce crystals to mitigate the coherent optical transition radiation due to the microbunching instability through the use of band-pass filters and specially timed cameras.

INTRODUCTION

A transverse beam profiling station for the characterization of low-power, tune-up beam has been initially tested at the A0 Photoinjector (A0PI) [1]. The A0PI consists of an L-band rf gun followed by a 9-cell superconducting rf capture cavity which combine to produce a 15 MeV electron beam. The charge per micropulse typically ranges from 20-500 pC and generates beam sigma sizes of 45-250 μm. The stations will be installed this summer at the Advanced Superconducting Test Accelerator (ASTA), and the intercepting radiation converter screens will be used to characterize the low-power, tune-up beam [2]. Either a 1 μm thin Al foil for optical transition radiation (OTR) or a 100 μm thick single-crystal scintillator of either YAG:Ce or LYSO:Ce oriented normal to the beam and followed by a 45° mirror will be inserted into the beamline. The radiation is then transported through light-tight tubes to a 5 MegaPixel CCD camera, as shown in Fig. 1.

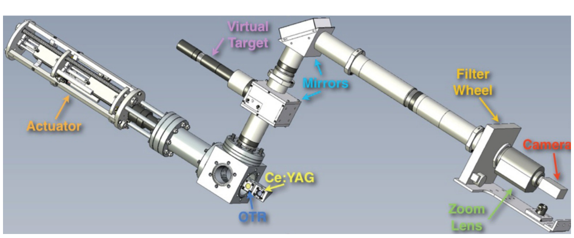

Figure 1: Drawing of the transverse profile monitor showing the actuator, screens, optical transport, filter wheel and camera. (Image courtesy of RadiaBeam Technologies).

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Table 1: Comparison of Scintillators for Use in the Transverse Profile Monitor [3, 4, 5]

Properties	YAG:Ce	LYSO:Ce
Index of Refraction	1.82	1.82
Wavelength of Peak (nm)	525	420
Density (g/cm^3)	4.57	7.1
Photon Yield (photons/MeV)	18×10^3	25×10^3
Scintillation Efficiency	45%	73%
Effective Atomic #	35	66

RADIATION CONVERTER SCREENS

Each station is equipped with both an OTR foil and single crystal of either YAG:Ce (Ce^{3+} doped $Y_3Al_5O_{12}$) or LYSO:Ce (Ce^{3+} doped $(Lu,Y)_2SiO_5$). Table 1 lists relevant scintillator properties, such as the peak wavelength being shifted from 525 nm to 420 nm. Experimental results comparing YAG:Ce and LYSO:Ce performances at low charge are presented in Table 2. From the table, we can see that YAG:Ce and LYSO:Ce crystals both give similar sizes of 46 μm and 54 μm, respectively, while maintaining equivalent intensities as indicated by the amplitudes determined by a Gaussian fit to the projected profiles.

Table 2: Low-charge image projection data from both crystals. The YAG:Ce data were taken using 1 bunch with the YLF laser while the LYSO:Ce data were taken using 1 bunch generated using the UV component of the Ti:Sapph as the drive laser.

	YAG:Ce		LYSO:Ce	
	Size(μm)	Amp.	Size(μm)	Amp.
100 pC	131 ± 1.1	98.6 ± 1.4	83 ± 1.3	112 ± 1.1
20 pC	46 ± 1.2	41.4 ± 1.1	54 ± 0.1	48.6 ± 0.5

Heating & Saturation

For beam consisting of 4000 pulses each with charge of 5 nC repeated every 1 Hz the estimated stress fracture limit of 30-40 MPa in YAG:Ce will not be reached at 20 MeV, as shown in Fig. 2 [6]. Of course, to avoid the fracture limit at 1 MHz micropulse rate it is best to use less than 100, 5 nC pulses which is already enough light to saturate the

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CCD 1000 times over. We expect the ILC-like 3.2 nC per micropulse charge with a focus of $\sigma < 100\ \mu$m will result in scintillator saturation. This situation is expected during a quadrupole scan for emittance measurements at 250 MeV [7]. Although incoherent OTR yields only ∼1 photon/100 incident electrons, it is linear in response, making it suitable for beam sizes to be measured in the high-charge areal density crystal saturation range [8].

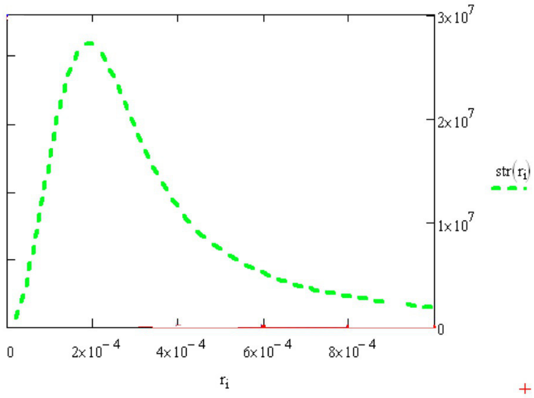


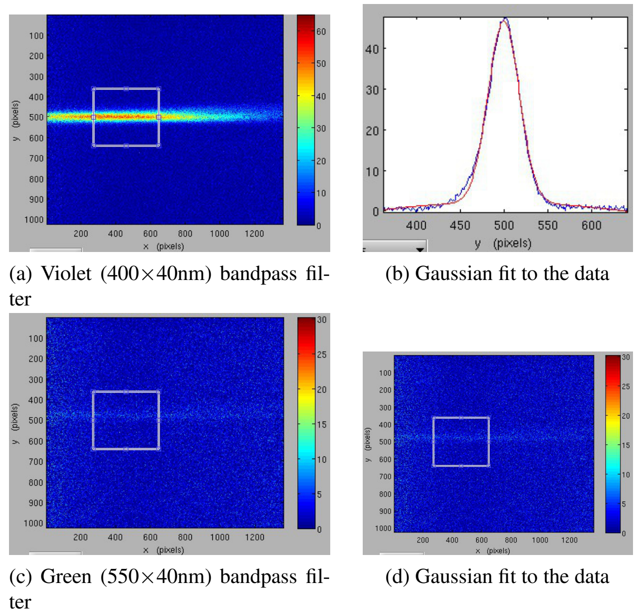
Figure 2: Plot of stress (Pascals) (right axis) versus radius (m) for a 100 μm thick YAG screen. Simulation results of 4000 pulses of 5 nC beam with average spot size of 100 μm RMS at energy of 20 MeV [6].

MICROBUNCHING INSTABILITY

Laser-driven rf guns that produce ultra-bright, low emittance electron beams have shown evidence of coherent optical transition radiation (COTR) in uncompressed and compressed electron bunches [9, 10, 11, 12]. In anticipation of increased COTR due to this microbunching instability in the compressed beam locations at ASTA/NML we expect to use the LYSO:Ce scintillator as our primary transverse beam profile diagnostic.

Bandpass Filters

Previous studies show the spectrum of COTR to be enhanced in the red wavelengths [12]. In anticipation of this, we have selected LYSO:Ce crystals, which have peaked emission around 420 nm, for diagnostic stations following the chicane. Fig. 3 shows the result of our bandpass filter tests. We made a horizontal stripe of 150 pC beam and recorded images with a 400×40 nm bandpass filter as shown in Fig. 3a. Fig. 3b shows the data in blue with a Gaussian fit in red. For the following figures 3c and 3d, we replaced the violet filter with a bandpass filter of 550×40 nm and observed a much reduced intensity, as expected. Each diagnostic station will have two filter wheels outfitted with bandpass and neutral density filters to allow us to selectively image in the 400 nm regime. This should reduce the contributions to the beam size from COTR.



(a) Violet (400×40nm) bandpass filter

(b) Gaussian fit to the data

(c) Green (550×40nm) bandpass filter

(d) Gaussian fit to the data

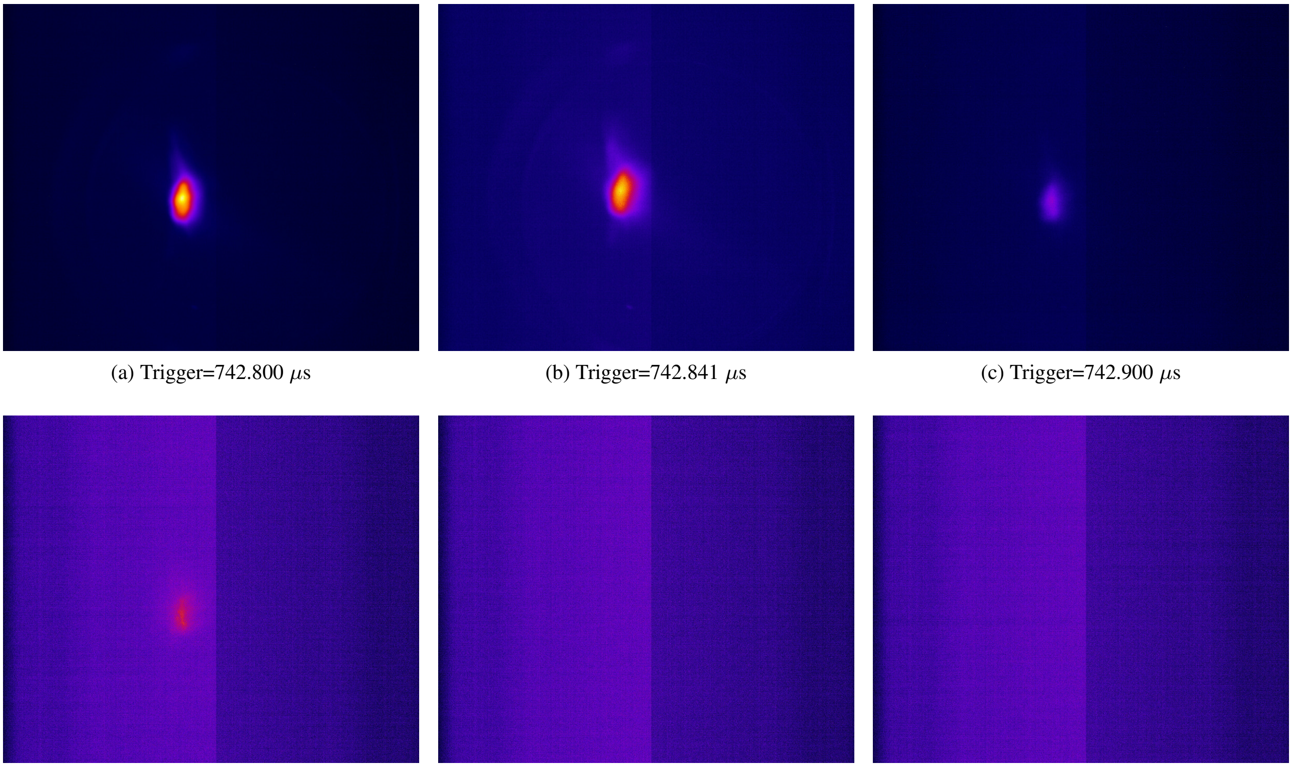
Figure 3: Bandpass filter data showing LYSO:Ce scintillating in the desired 400nm range.

Camera Shutter and Triggering

The final test we conducted was a trigger test of the camera to show that we could image beam with the scintillators after the almost instantaneous peak of OTR had been emitted. The exposure time was set to 10 μs to provide an electronic shutter. Through our controls system we are able to control the camera trigger in order to delay from the initial value of 748.8 μs, see Fig. 4a and 4d, showing LYSO:Ce and OTR images, respectively. Unfortunately the control does not allow for less than 100 ns changes so we added a cable delay of 41 ns as shown in Figures 4b and 4e. In these images we can see the LYSO:Ce is still visible while the OTR signal is gone. In the final set of images we have set the camera trigger to 742.9 μs to show the slower decay rate of the crystal still yields a visible image, see Figures 4c and 4f. This method will work for a single micropulse at 5 Hz or with a fast kicker for selecting a single micropulse out of the 3 MHz pulse train.

CONCLUSION

Based upon tests conducted at the A0PI, we can conclude that the LYSO:Ce crystal will be a suitable alternative to the YAG:Ce crystal for beam imaging. The YAG:Ce and LYSO:Ce crystals both offer similar performance characteristics for low charge beam, but LYSO:Ce combined with a violet bandpass filter has the added benefit of mitigating the COTR due to the microbunching instability in beam images. The OTR screen can also be used to avoid the scintillator saturation at high areal charge density and the thin foils generate less beam scattering. If the use of bandpass filters, CCD shutter timing and LYSO:Ce are not enough to reduce the COTR due to the microbunching instability, we



(a) Trigger=742.800 μs (b) Trigger=742.841 μs (c) Trigger=742.900 μs

(d) Trigger=742.800 μs (e) Trigger=742.841 μs (f) Trigger=742.900 μs

Figure 4: Comparision of LYSO:Ce (top row) and OTR (bottom row) intensity versus camera trigger timing.

could use a gated, intensified camera [11].

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